The Implications of Climate Change for the Environment Agency

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Statement of use
This report provides useful climate change information for a wide cross-section of Agency staff. Its analysis and recommendations will also form the basis for Agency policy responses at the Corporate, Regional and Functional levels.

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FOREWORD

In its Environmental Strategy the Agency identified a number of key areas of concern, upon which it should develop its corporate strategic planning, in order to make real changes to the environment in a way with which others could readily identify. The first of these concerns was that of climate change. It is the principal 'natural' stress upon the state of the environment and will affect the others, particularly rainfall patterns, the frequency of severe weather conditions, energy use, and changes in social behaviour. It will also affect an evaluation of the state of the environment in many ways, including water resources, biodiversity, the ability to comply with environmental standards and targets, human health related aspects, and landscape and other aesthetic considerations. But it is also a problem which the Agency needs to approach in a measured way, both because of its scale in space and time, and because of the Agency's complicated role in the many factors involved. This report therefore attempts simply to help map out some of the issues affecting the UK and highlight what the Agency should be doing about it.

The climate has of course never stood still; it has always been changing. But there are two aspects of the current situation which makes it somewhat different from the past. The first is the realisation that the climate could be changing globally because of human activity and that a change in this activity, now, could therefore affect the climate in different ways in the future. The second is the fact that the rate at which the climate is currently changing, irrespective of the cause, requires considerable thought and action in order to safe-guard the use of the UK environment in a sustainable way. The Agency is involved in both aspects : addressing the likely cause, and adapting to its potential effects. And it needs to move quickly in order to make the most of its considerable talents in both of these areas.

DR R J PENTREATH
Chief Scientist

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GLOSSARY

AGBM	*Ad hoc Group on the Berlin Mandate*
AIJ	*Activities Implemented Jointly*
BAT	*Best Available Technology*
BATNEEC	*Best Available Techniques Not Entailing Excessive Cost*
BPEO	*Best Practicable Environmental Option*
BREF	*BAT Reference notes*
BOD	*Biological Oxygen Demand*
CAP	*Common Agricultural Policy*
CBI	*Confederation of British Industry*
CCIRG	*Climate Change Impacts Review Group*
CCGT	*Combined Cycle gas Turbines*
CDM	*Clean Development Mechanism*
CFCS	*Chloroflurocarbons*
CH_4	*Methane*
CHP	*Combined Heat and Power*
CO	*Carbon Monoxide*
COP	*Conference of Parties*
CO_2	*Carbon Dioxide*
CRU	*Climatic Research Unit (University of East Anglia)*
DDC	*Data Distribution Centre (CRU)*
DETR	*Department of Environment, Transport and the Regions*
DoE	*Department of Environment*
DTI	*Department of Trade and Industry*
EITS	*Economies in Transition*
EC	*Economic Community*
ECAP	*Eutrophication Control Action Plans*
EU	*European Union*
FCO	*Foreign Commonwealth Office*
FGD	*Flue Gas Desulpherisation*
GCM	*General Circulation Models*
GCI	*Global Commons Institute*
GHG	*Greenhouse Gases*
GWPS	*Global Warming Potential*
HCFCS	*Hydrochlorofluorocarbons*
IPCC	*Inter-governmental Panel on Climate Change*
ISR	*Inventory of Sources and Releases*
JI	*Joint Implementation*
LEAPS	*Local Environmental Agency Plans*
MAFF	*Ministry of Agriculture, Fisheries and Food*
NOx	*Nitrogen Oxides*
N_2O	*Nitrous Oxides*
NFFO	*Non-Fossil Fuel Obligation*
NMVOC	*Non-Methane Volatile Organic Compounds*
NPV	*Net Present Value*
OCGT	*Open Gas Cycle Turbine*
OECD	*Organisation of Economic Cooperation and Development*
OFWAT	*Office of Water Services*
PAGN	*Project Appraisal Guidance Notes*

PFCS	*Perfluorocarbons*
PIR	*Process Industries Regulation*
SAR	*Second Assessment Report*
SF_6	*Sulphur Hexafluoride*
UNFCCC	*United Nations Framework Convention of Climate Change*
UNGASS	*United Nations General Assembly Session (or Earth Summit II)*
UKCIP	*UK Climate Impacts Programme*
VOCS	*Volatile Organic Compounds*

KEY RECOMMENDATIONS

This study has focused on the science of climate change, the political background to the international commitment to reduce emissions of greenhouse gases, the drivers behind emissions of greenhouse gases in the UK, and the possible impacts of climate change on natural resources and Agency Functions. This has formed the basis for the mitigation and adaptation response options developed in Chapters 6, 7 and 8.

The following is a summary of the key response options identified in the study.

STRATEGY FOR RESPONDING TO CLIMATE CHANGE

Take the Initiative

Research
The UK Climate Impacts Programme (UKCIP) provides the best forum for the Agency to develop collaborative research programmes with a number of other organisations. Developing "impact scenarios" would be a useful contribution of the Agency to UKCIP and would assist the Agency in taking the initiative in the development of appropriate and adaptive managerial responses.

Emissions Reduction
The UK emissions reduction targets set for the period up to 2012 are clearly only a first step in a much more ambitious programme that will be required over the longer term by the international community. The Environment Agency has two broad options.

- directly influencing private sector emitters of green house gases through its role in the IPPC process. The integration of energy efficiency into the IPPC and Best Available Technology process will require some further work in developing methods of measurement and monitoring of green house gases, and for comparing the technical and economic tradeoffs between different technologies, particularly in the energy sector. The monitoring and enforcement role could extend to the use of economic instruments such as energy taxes and emissions trading.
- indirectly influencing or contributing to UK Government policy affecting climate change emissions (renewables and technology transfer programmes) and consumers (through awareness raising initiatives). These indirect actions would involve extending the interpretation of the Agency's current roles and responsibilities.

Adaptation
Uncertainty exists in projections of future greenhouse gas emissions and consequent climate change scenarios, in 'down-scaling' the scenarios to the finer scales required for impact studies and in translating climate changes to, say, changes in river flow. It will be important for the Agency to develop decision tools for dealing with uncertainty.

A response strategy will be needed to reflect a hierarchy of priorities. Not all of the issues need a strategic response now. For some areas, the immediate response will be developing decision making techniques. For others, immediate action will be required, particularly in managing conflicts between competing users of scarce resources. For several areas such as air pollution and fisheries the strategy may be to ‘wait and see’ while for others the Agency is already taking actions consistent with likely future changes.

Work with Others

It will be important that the Agency works closely with the DETR in helping to deliver the overall national programme. It should become more involved in the development of policy responses. Because of the international nature of the climate change policy response, this may involve the Agency becoming involved both at a European and international level in developing these policy ideas.

The national response to climate change will involve all sectors of society and it will be important for the Agency to work with a wide range of these other organisations. The Agency will need to build and maintain consensus with the users of the resources that it manages, wherever possible.

Maintain Credibility

There is a need for a much clearer message from the Agency regarding our current understanding of climate change. The vast majority of scientists are unwilling at this stage to ascribe any specific event to climate change. The Agency needs to assist in raising the understanding throughout society of climate change and its potential impacts on the UK.

There is potential for the climate change management conflict to be raised with respect to other issues particularly flood management and conflicts over water availability.

KEY RESPONSES FOR MITIGATION

General

In order to assess the carbon savings that the Agency can implement within its current roles and the potential for carbon savings from developing its roles, emissions must be measures accurately and carbon savings from mitigation strategies monitored. Barriers to successful implementation of mitigation strategies should be identified.

Conventional appraisal models need to be adapted to reflect risk and uncertainly.

The Agency can contribute to the climate programme through its role as regulator and through input into the development of government policy. Key mitigation responses are detailed below.

Regulatory role

Integrated Pollution Prevention and Control
The Agency has a significant potential role to play in mitigation policy because of the large proportion of total emissions that are emitted from processes licensed by it. An important issue for the Agency is to consider the trade-offs between energy use and controls of other pollutants.

Waste Management
The Agency's key role will be in influencing the government's waste management strategy in measures to discourage disposal to landfill and the capture and use of landfill gas. This can be done through the promotion of life cycle assessment for waste management and the comparison of strategies for a range of environmental impacts, including greenhouse gases from all sources, including transport, energy use and recovery as well as methane from landfills.

Market based instruments
The Agency has a potential role in domestic implementation of the mechanisms, particularly with respect to development of emissions inventories, monitoring industry emissions and, in the case of tradeable permits, enforcement of emission trades.

For trading of greenhouse emission rights, the monitoring task is to ensure that a legal entity (firm) that has a duty to hold permits to cover all of its emissions is in compliance with this. This involves establishing and using a mechanism for emission inventories at the firm or plant level. There will also be a potential role for the Agency in allocating emission permits. If emission permits are given to firms in proportion to some level of historical emissions (grandfathered) there will be a need for a record of historical emissions. There are a number of efforts being started to establish a pilot trading system in the UK. The Agency might contribute to these particularly in terms of their expertise in monitoring and enforcement issues.

For project-based trading, monitoring is required to guarantee the emission reductions from a specific project. Depending on the domestic rules set, some proof is likely to be required that the project is additional to what would have happened under a business as usual scenario.

The March 1999 budget announced the introduction of a tax on the business use of energy. Energy intensive sites that agree targets for improving their energy efficiency will have reduced rates of tax levied on them. The Agency could provide a role in monitoring the effectiveness of the tax and the compliance of energy intensive industries with their energy efficiency targets. This would help inform the government of the likely potential emission savings that might come from the imposition of the tax.

Development of Government Policy

The Agency could enhance the development of government policy for climate change mitigation in a number of ways:

- through providing a more detailed analysis of technical and policy options;
- through the development of technology databases, eg in support of regulated approaches to emission reduction;
- in planning issues, particularly for trade-offs between local disamenities relating to renewable energy and the global benefits of greenhouse gas emission reduction. The Agency could assess the trade-offs between planting energy crops and the costs accruing to other environmental resources.

The Agency could develop an influencing role in the following areas:

- development of an in-house Greenhouse Gas Reduction Plan;
- encourage the transfer of technology to developing countries. Agency staff have considerable expertise in technologies that would be relevant in many other countries and could usefully contribute to the UK's efforts in technology transfer in association with other departments and international organisations including the Climate Technology Initiative, set up by developed country Parties to the UNFCCC.
- the potential for the Agency to encourage Resource Demand Management (RDM) to encourage energy conservation and efficiency improvements;

KEY RESPONSES FOR ADAPTATION

Water Resources

Risk and uncertainty generated by climate change needs to be incorporated into Agency planning time frames for large projects such as reservoir construction, and the planning of certain demand side management measures.

All new abstraction licences are time limited. This should be extended to all existing abstractions.

The Government's consultation paper 'Review of the Water Abstraction Licensing System in England and Wales (1998)', proposes options for water abstraction such as placing water companies under an enforceable duty to conserve water in carrying out their functions, using the price mechanism to reflect different levels of water scarcity through trading in water abstraction licences and placing all abstractors under an enforceable duty to use water abstracted in an efficient manner.

One method of using the price system is through implementation of a trading system for abstraction licences. The quantity of trading licences on the market will reflect the target level of water available for abstraction. Allocation decisions made on the basis of price must consider lower income groups where the negative income effects would be highest.

Water Quality
Discharge consents are determined almost exclusively on the basis of environmental modelling of the effects of the discharges and some consideration of the costs of abatement. The environmental modelling must be adapted to incorporate the uncertainties and impacts of climate change, and the changes in river conditions.

An Agency National Plan for Water Quality will be developed for the maintenance and future improvement of water quality. This should take into account the impacts of climate change on other functions, their response, and their corresponding impact on water quality.

Flood control
The Agency is applying more risk based approaches to management and planning supported by the establishment of a National Centre for Risk Analysis and Option Appraisal. The inclusions of uncertainty surrounding climate change impacts will be key in appraisal and planning for flood control options and strategies.

Public information and awareness of flood risk would be useful step in adapting demand away from housing in risky areas, eg floodplains, to less risky areas. Increased information would help direct local government planning for housing to areas less prone to flooding.

Conservation
One of the most important elements of a conservation strategy will be to come to a better understanding of the concept of what should be maintained. Should the Agency seek to protect ecosystems and habitats in their original (pre-climate change) state, allow ecological change in response to climate change whilst ensuring that the ecosystem is “natural” for that location and climatic condition or what people like.

Climate change will occur too rapidly for some species to adapt in an evolutionary sense. Measures that ease the migration of species, such as provision of habitat corridors and the translocation of species may be needed instead. Special attention could be focused on those areas that are particularly vulnerable to climate change such as the wetlands in Southern England, coastal marshes and montane communities.

It is important to maintain the collection of baseline environmental data to monitor change and allow ongoing adaptation of management practices to the changing environment.

Fisheries
Research must define ecologically acceptable river flows to protect fish stocks and fisheries, identify potential impacts (and mitigation) of changing land use and rainfall patterns on key habitats, such as salmonid spawning gravels and determine ecologically acceptable levels of sub lethal components of discharges such as endocrine disruptors.

There is a need for a robust evaluation of the social and economic benefits accrued from inland fisheries so that they can be defended against the future challenges associated with climate change impacts such as changes in availability of water resources.

The Function should develop and disseminate best practice for fishery managers that provides options for a sustainable response to the projected climate change.

Long-term monitoring of the fish communities will enable changes to be identified and allow the benefits from adaptive management approaches to be evaluated.

Recreation
At this stage the most important strategic response by the Agency is developing a better decision making process for priority setting with respect to multiple users of scarce resources, particularly waterways.

It will be important to provide accessible and attractive recreational opportunities close to where people live, in order to mitigate transport emissions associated with increased leisure time. This may require improved opportunities to access and enjoy rivers, lakes and reservoirs in and around inland towns and cities in order to dissuade people from travelling to the coast.

Navigation
Management techniques that co-ordinate different river users in a sustainable manner need to be developed.

1 OBJECTIVES OF THE STUDY

1.1 BACKGROUND

This report has been produced by Environmental Resources Management (ERM) in association with the Climatic Research Unit (CRU), University of East Anglia.

It examines the implications of climate change for the Environment Agency (hence referred to as the Agency) which includes:

- *Greenhouse Gas Reduction* - under DETR's co-ordination, the UK government is developing a strategy which will enable it to achieve the quantified emission limitation and reduction commitments it has been agreed to fulfil under the Kyoto Protocol. The Agency will contribute towards the achievement of these commitments through its regulatory and other activities.

- *Climate Change Impacts* - climate change is expected to have physical impacts on the UK which may affect the Agency's ability to achieve its objectives.

These are two distinct issues for the Agency, and each will be discussed in turn in this report.

Climate change is acknowledged as an important element of the Agency's future strategy.(1) The Strategy lists climate change as one of nine principal and immediate environmental concerns that the Agency is addressing. In order to address this topic, the Agency has stated that it will:

- help to ensure that the Government's greenhouse gas emission reduction targets are met;

- develop methods to improve estimates of the emission of methane into the atmosphere from landfill sites;

- promote tax incentives to reduce energy production from burning fossil fuels;

- set an example by reducing its own energy and fossil fuel consumption;

- invest in research to predict the likely effects of climate change on the environment of England and Wales and how to manage them;

(1) Agency (1997) An Environmental Strategy for the Millennium and Beyond.

- provide improved mapping of low-lying coastal areas at risk from sea-level changes;
- develop techniques to identify changes in plant life, using remote sensing techniques, to measure the effects of different weather patterns in sensitive areas; and
- contribute knowledge and expertise to national and international forums dealing with climate change.

This report responds to this set of issues through:

- examining the ways in which the Agency can help the government to meet its international commitments relating to reporting (inventories and projections) and in meeting targets;
- examining the ways in which the Agency can contribute to the ongoing public policy process to respond to climate change;
- developing a better understanding of the effects of climate change in England and Wales and ways in which the Agency can help to manage or adapt to these changes or to monitor the development of climate change.

1.2 STRUCTURE OF THE REPORT

Climate change is a theme which covers a great many aspects of the Agency's activities. The following structure has been used to set out the different facets of this subject. Emphasis has been placed on possible response options and decision making for climate change strategies under uncertainty.

- a description of the Agency, its responsibilities and remit for different environmental resources / issues is given in *Section 2;*
- a description of the political context of the emissions reduction agenda and the range of UK responses is outlined in *Section 3;*
- a description of the global and regional climatology issues is outlined in *Section 4;*
- human activities and emissions in the UK and the resulting pressure on the environment is addressed in *Section 4*;
- impacts resulting from climate change are addressed in *Section 5*;
- response options for emissions reductions and impacts management open to the Agency are discussed in *Sections 6-8.*

2 RESPONSIBILITIES AND REMITS OF THE AGENCY

2.1 THE AGENCY

2.1.1 Agency Objectives

The principal aim of the Agency is to 'protect and enhance' the environment, to make a contribution towards attaining the objective of sustainable development.

A number of statutory objectives determine how the Agency pursues the management of the environment. Two relevant objectives (1) , with regards to the impacts of climate change on the Agency's functions, are to:

- "adopt across all our functions an integrated approach to environmental protection and enhancement which considers impacts of substances and activities on all environmental media and on natural resources"

- "develop approaches which deliver environmental requirements and goals without imposing excessive cost."

The Agency adopts a long term strategic objective to anticipate environmental risks and drivers of environmental change. Climate change impacts on a very broad range of the Agency's functions. The assessment of costs and benefits of response actions needs to take into account the uncertainty of impact across time and space.

2.1.2 Structure of the Agency

The Agency has a decentralised structure comprising Head Office, eight Regions (this includes Wales) and twenty six Areas.

The main structure is provided by the twenty six Areas. Each Area has integrated teams comprising environmental protection; environmental planning; flood defence and water resources; fisheries, ecology and recreation. Areas are managed and supported by eight Regions that are responsible for strategic leadership of each Region and its Areas, and for contributing to national policy. Areas also have the responsibility for developing and producing Local Environmental Agency Plans (LEAPs) which are Agency integrated management plans for identifying, assessing, prioritising and solving local environmental issues related to Agency functions.

Head Office provides a coordinating, policy and strategic advisory role and is the main point of interaction of the Agency with government, particularly the DETR.

(1) Environment Act 1995, Section 4 (2)

Responsibility for overall climate change policy development lies with the Sustainable Development (SD) Function. The SD function will seek to develop closer ties with the DETR in climate change policy development as well as with other bodies interested in sharing expertise and best practice. A key objective for the SD function will be to integrate climate change into other environmental themes. A climate change network is due to be set-up in 1999 to improve communications around the Agency concerning developments within and outside the Agency.

The Agency's research and development programme is used, at one level, to improve its understanding of the linkages between environmental and economic factors and to research and develop new tools and techniques at strategic, policy and operational levels.

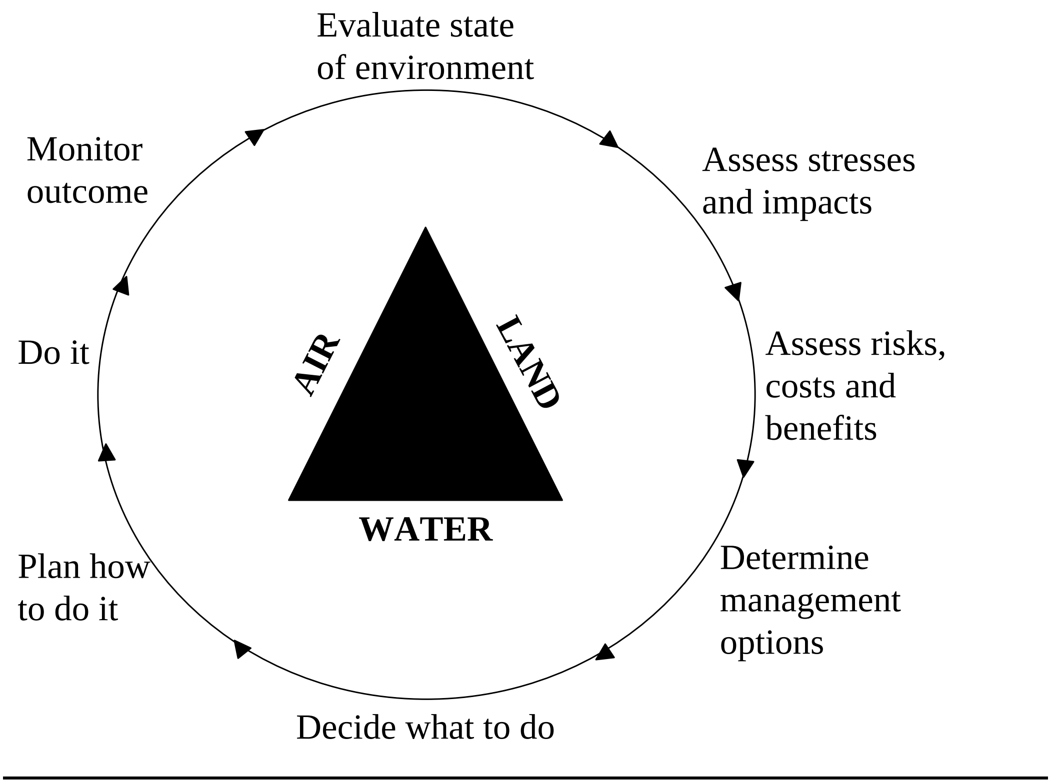
Coordinated management for addressing climate change will be needed within this organisational matrix.

2.1.3 A Framework Approach

In addressing the environment management cycle (*Figure 2.1*), the Agency has developed four frameworks which formalise its approach:

i. Viewpoints;
ii. Stresses and Strains;
iii. Risks and Values;
iv. Delivering a Better Environment.

Figure 2.1 The Environmental Management Cycle



Viewpoints on the Environment provides a structure for monitoring and assessing the environment, through focusing on six issue categories:

- land-use and resources;
- biological populations, communities and biodiversity;
- standards and targets;
- health of the environment;
- long term reference sites;
- aesthetic quality.

It provides the means for identifying the basic questions that need to be addressed in assessing the rate of progress towards achieving sustainable development objectives.

Climate change is expected to affect the resources that are the focus of *Viewpoints on the Environment*, for example, land use and resources, biological populations, communities and biodiversity. The monitoring task requires an understanding of expected outcomes with respect to these resources and to monitor changes over time.

There are a set of agreed objectives internationally and domestically which provide short to medium term requirements of policy on the limitation and reduction of emissions. These are regarded as a step on the way towards more longer term policy requirements to tackle climate change. Objectives relating to adaptation are more of a domestic than an international concern. These issues are outlined in more detail in *Section 7*.

Stresses and Strains on the Environment offers a framework for thinking about the pressures and associated impacts on the environment, and to assess the success of Agency functions in alleviating or reducing pressures and impacts. It provides the basis for assessing priorities for action and charting progress of environmental management plans and targets. The stresses and strains framework covers:

- natural forces;
- societal influences;
- abstractions and removals;
- usage releases and discharges;
- waste arisings and disposals;
- illegal practices.

Risks and Values responds to the previous two frameworks by providing a consistent basis for assessing risks and cost-benefit values of impacts and associated response options. Various tools and techniques are needed to carry out these assessments. Development of the tools and techniques is carried out at the Agency's National Centre for Risk Assessment and Options Appraisal.

The types of risks the Agency must assess are as follows:

- risks which are inherent but can be reduced, for example, risks of flooding or drought;
- risks which are new and arise from the Agency's powers to issue environmental licences for new processes and sites;
- risks which may not arise until some time in the future, such as impacts from climate change;
- perceived risks, which may differ markedly from the real risks and may impact on the valuation of environmental resources.

Screening of potential risks provides a technique for deciding on an appropriate level of risk assessment. Risks are categorised and prioritised. Further detailed assessment may be given to priority risks. Specific risk models may need to be constructed for complex issues. Assessment of response options can use cost effectiveness analysis, costs benefit analysis or multi-attribute techniques. Societal preferences for environmental resources are taken into account in cost-benefit analysis and multi-attribute analysis.

Climate change complicates the analysis of risk and the associated costs and benefits of response options due to the uncertainty in the severity and timing of impacts. General Circulation Models (GCM) are the main tool available for analysis of impacts, *see Section 4*, although these models offer less certainty of results for local impacts. The UK Climate Impacts Programme (UKCIP) provides a national forum for the development of impact assessments, *see Section 8.3.1*.

Delivering a Better Environment comprises the principal management approaches and techniques that enable the Agency to deliver the protection or improvement of the environment. The framework seeks to deliver an integrated response using a thematic approach. This enables the Agency to secure improvements either directly, by working in collaboration with other organisations, or by influencing the types and nature of activities pursued by others. The themes are as follows:

- climate change;
- regulating major industries;
- improving air quality;
- managing waste;
- managing water resources;
- delivering integrated river basin management;
- conserving the land;
- managing freshwater fisheries;
- enhancing bio-diversity.

Climate change is an over-arching issue which will influence every aspect of the Agency's work. The Agency will need to assess how pressures, impacts and priorities for action will change under the impacts of climate change. These impacts are outlined in more detail in *Section 5*.

Prioritisation of issues and actions under each of these themes will require close co-operation between the Agency's business functions and will need to draw upon information derived from the *Viewpoints* and *Stresses and Strains* frameworks, and utilise the tools and techniques being developed through the *Risks and Values* framework.

The Environmental Strategy is currently being reviewed as part of an on-going process to improve its ability to help deliver a better environment.

2.1.4 The Agency and Climate Change

Climate change is an issue that has clear resonance with the Agency in terms of:

- its overall objectives and the pursuit of sustainable development;
- the role the Agency can play in limiting emissions of greenhouse gases consistent with national and international programmes and objectives for mitigating the causes of climate change;
- the impacts of climate change on the resources and environmental attributes that it manages.

The Framework approach that the Agency has developed provides a structure for thinking about this issue that covers the underlying causes and the likely solutions in the short and long terms. It also recognises that many of these causes of environmental stress lie beyond the scope of the Agency's statutory powers. The Agency therefore aims to approach the issue of climate change as it affects England and Wales holistically rather than in the narrow terms of its functional duties. The Agency is developing relationships with other agencies, both statutory and otherwise, to forge a collective response to this cross-cutting issue.

The Agency also needs to ensure that it responds in an integrated manner across its various duties and responsibilities.

The following section offers a brief summary of the Agency's responsibilities for environmental issues that potentially could be impacted by climate change.

2.2 STATUTORY DUTIES AND ACTIVITIES OF THE AGENCY

2.2.1 *Water Resources*

Under the Water Resources Act 1991, Agency duties relating to water resources include:

- taking action, as and when necessary, to conserve, re-distribute or otherwise augment water resources in England and Wales;
- entering into and maintaining water resources operating arrangements with water companies where necessary;
- publishing information on the demand for water and available resources;
- administering a system of licensing abstractions and impoundments;
- enforcing abstraction licence law.

The principle aim is to ensure that existing management and future development of water resources is carried out sustainably. The principle mechanism for achieving sustainable development of water resources is through the Agency's regulation of water abstraction.

Water resources are vulnerable to changes in precipitation and temperature induced by climate change. Water users, such as the agricultural sector, are particularly sensitive to climate change.

2.2.2 *Water Quality*

Responsibilities for water quality derive principally from the Water Act 1989, the Environmental Protection Act 1990, the Water Resources Act 1991 and the Environment Act 1995. Trade effluent control from privatised water companies falls under the Water Industry Act 1991. EU Directives also play a major role in the regulation of water quality.

The Agency has the following duties:

- to ensure that statutory water quality objectives are met and that pollution is monitored;
- to ensure that provisions to prevent effluent discharges without the consent of the Agency are enforced;

- to maintain and make available to the public a register, recording applications for consents to discharge, records of consents given, samples of water or effluent and other related information. The power exists to issue and enforce a variety of notices where action is required to reduce the risk of pollution.

Climate change will affect water quality through its impact on river flows as a result of changes in precipitation and the effects of temperature on evapotranspiration rates. Increased precipitation and temperature together with an increase in extreme events will induce greater land surface run-off and water drainage. An increase in temperatures is likely to affect the activity of pathogenic organisms in water sources.

2.2.3 Flood Defence

The flood defence powers, duties and responsibilities of the Agency are set out in the Water Resources Act 1991, Land Drainage Act 1991, and the Environment Act 1995.

The Agency has a statutory duty to exercise general supervision over all flood defence matters and has specific responsibilities for rivers and for sea defences in areas that are not privately owned. The Agency has:

- a major operational role to maintain, operate and improve flood defences where appropriate;
- responsibilities to disseminate flood warnings directly to the public;
- powers to grant consent for certain works that may affect watercourses and flood defence;
- the power to build defences to reduce the risk of flooding, including the replacement of defences reaching the end of their effective life.

Environmental assessment is an integral part of the Agency function, together with decision-making based on cost-benefit analysis and widespread consultation.

Currently guidance on how to take account of climate change is offered in:

- a Joint Circular from the Department of the Environment, Ministry of Agriculture, Fisheries and Food (MAFF) and the Welsh Office.(1) It provides guidance to local planning authorities and others on the arrangements for ensuring that planning decisions take account of any risk of flooding,

(1) DoE Circular 30/92, Development and Flood Risk (WO 68/92, MAFF FD1/92), 16 December 1992.

whether inland or coastal. This includes suggestions on how to take account of climate change in designing coastal defences. Two other key documents are:

- Project Appraisal Guidance Notes (PAGN)(1) which provide guidance for the economic appraisal of schemes, sensitivity testing and risk assessment;

- a MAFF strategy document(2) for flood and coastal defence, which identifies significant risks for sea defences.

Climate change is expected to affect flooding in both inland areas associated with rainfall events and coastal areas as a result of sea level rise and storm events.

2.2.4 Conservation

Conservation objectives are pursued through the exercise of statutory powers and duties in other Functions. Although the Agency is not directly responsible for site and species protection, it has two primary statutory duties under the Environment Act:

1. to 'further' conservation whenever water management functions are carried out and to have regard to conservation whenever pollution prevention control functions are carried out;

2. to promote conservation of the aquatic environment.

The Agency also has a legislative duty to consult the relevant conservation bodies regarding any of its activities which could affect sites of special scientific interest, and has been specifically required to take into account both officially designated and non-designated sites.

The Agency's conservation remit covers wildlife, landscape and physiological features that are directly or indirectly affected by regulatory, operational and other activities.

Climate change is likely to result in changes in the composition of species, migration and invasions of species, losses and extinctions, outbreaks of pests and diseases and landscape and habitat changes.

(1) MAFF/WO Project Appraisal Guidance Notes, 1993

(2) MAFF/WO Strategy for Flood and Coastal Defence in England and Wales, 1993

2.2.5 *Fisheries*

Under the Environment Act 1995, the Agency has a general duty to maintain, improve and develop salmon, trout, freshwater fish and eel fisheries with the aim of optimising the social and economic benefits from the sustainable exploitation of these fish stocks.
The Agency has specific duties relating to the potential impact on fisheries through the Agency's regulation of water abstraction, water quality and land drainage works. Wider environmental duties relate to taking account of features of special interest, the need to further their conservation when carrying out water management functions and to have regard to their conservation when carrying out pollution prevention and control functions.

The status of fish communities forms the basis for setting water quality objectives for designated stretches of water (the EC freshwater Fish Directive, 1978). The EC proposed Water Framework Directive incorporates surface water quality objectives based on similar ecological measures.

Principal powers related to this activity are:

- regulation of fishing activity;
- enforcement of primary fisheries legislation and bylaws;
- ensuring the free passage of Atlantic salmon and migratory trout;
- controlling the movement and introduction of fish;
- controlling fish disease;
- monitoring fisheries and fish stocks;
- raising income through licensing.

Climate change has the potential to affect fish survival and fecundity both in inland waters and the sea.

2.2.6 *Navigation*

The Agency's statutory responsibilities for navigations are covered under numerous national, local and Special Acts and Orders. Each of its navigations was created and operates under its own piece of legislation.

The Agency's navigation responsibilities are diverse, ranging from its roles as harbour and conservancy authority and a deep water navigation authority, to operational duties for navigation using land drainage bylaws. Navigation responsibilities are managed as an integral part of the river management process. Multi-functional staff ensure that water supply, water quality and flood defence requirements are met. The Agency has specific navigation responsibilities in four of its Regions, including the lengths of:

- the River Thames;
- the River Medway;
- several East Anglian rivers: the Nene, Great Ouse system, Welland, Ancholme, Glen and Stour;
- the Dee Estuary;
- the Harbour of Rye.

The Agency's navigations form an important part of the entire inland waterways network and coastal chain of harbours and estuaries. Its navigations are valuable resources in environmental, recreational, commercial, heritage and social terms. A significant part of the recreation and tourism industry relies on the existence of waterways.

Climate change is likely to affect navigations through inducing more frequent periods of low summer flow. Increased storm events will affect the navigability of rivers. Increased temperatures will spur greater vegetation growth within navigation channels.

2.2.7 Recreation

The Agency's statutory duties include:

- the enhancement of the natural beauty and amenity of inland and coastal waters;
- the promotion of the use of water and associated land for recreational purposes;
- the protection and conservation of buildings, sites and objects of archaeological, architectural, engineering or historic interest;
- having regard to the effects on the beauty or amenity of rural or urban areas;
- having regard to the effects on the economic and social well-being of local communities in rural areas;
- making best recreational use of land or water in the Agency's control.

Recreation responsibilities extend to all inland and coastal waters and associated land. Both formal and informal recreational activities are included in the Agency's remit.

Climate change has the potential to affect both the demand for recreation and the supply of suitable sites.

2.2.8 Process Industries Regulation (PIR)

The Agency's responsibilities for process industries regulation derive from the Environment Act 1995, the Environmental Protection Act 1990 and other related legislation such as the Water Industry Act 1991 and Conservation Regulations 1994.

PIR ensures that air, water and land are not harmed by the industrial processes that are regulated. Integrated Pollution Control (IPC) is a key instrument in delivering plans and obligations relating to pollutant emissions to air, land and water. IPC requires an assessment of all aspects of a process, including its design, operation and its impact on the environment as a whole. Its uses the principle of Best Available Techniques Not Entailing Excessive Cost (BATNEEC) to prevent or minimise polluting substance releases, within the context of assessing the Best Practicable Environmental Option (BPEO) for the releases. Integrated Pollution Prevention and Control (IPPC) will gradually take over IPC. This includes new requirements, such as energy efficiency Best Available Technology (BAT), *See Section 6.2.1 for more information*. Approximately 50% of the UK greenhouse gas emissions are produced by industries that are currently regulated by the Agency.

The Agency can use its regulatory powers to limit greenhouse gases, thus contributing towards the UK's domestic climate change mitigation strategy. In addition, climate change has the potential to affect pollution levels through the interaction of climatic conditions and air pollutants, and impacts on the water environment.

2.2.9 Waste Management

Waste management is regulated under numerous key pieces of legislation such as the Producer Responsibility Obligations Regulations 1997, Special Waste Regulations 1996, Environment Act 1995 and Waste Management Licensing Regulations 1994. The Agency carries forward the responsibilities of over eighty separate Waste Regulation Authorities to license the operation of waste disposal, recovery and treatment operations. The Agency is responsible for regulating the treatment, storage and disposal of controlled wastes, which consist of industrial, household and commercial waste. Other types of waste are controlled by powers from other statutes, for example, radioactive waste under the Radioactive Substances Act (RSA).

The Agency will also have a formal role in providing advice on the Government's waste strategy that is required under Article 7 of the EC Waste Framework Directive. The Agency will be responsible for implementing a scheme of 'producer responsibility' with regard to waste reduction by industry under the Environment Act.

A changing climate will affect the conditions for decomposition of waste including effects on water availability and temperature. In addition, the Agency has the potential to use its regulatory powers and other measures to limit and reduce emissions of methane emissions from waste facilities.

2.2.10 Summary

This section has summarised the Agency's roles and responsibilities and highlighted those most likely to be impacted by climate change:

- *water resources management*: changes in precipitation levels and evapotranspiration rates will affect the supply of water resources. Demand in climate sensitive water use sectors may increase;

- *water quality*: lower river flows, increased surface run off, increased water drainage and increased pathogenic organisms will impact negatively on water quality;

- *riverine and coastal flood defences*: increases in sea level rise and in storm events will make flood events more likely;

- *conservation of the natural and built environment*: impacts will derive from shifts in climate zones, as well as from changes in water resources, water quality, flood events and changes in demand for recreation;

- *fisheries management*: changes in the quantities of water resources, changes in water quality and land drainage works will impact on the survival and fecundity of fish populations;

- *navigation:* this function will be particularly affected by changes in the river levels, which may occur through decreased precipitation rates, increased abstraction rates and flood control works;

- *water based recreation*: demand for water-based recreation may increase due to higher temperatures. This may be compounded by changes in the supply of such recreational resources due to changes in the quantities of water resources, changes in water quality, flood control works and changes in the conservation status of some of these sites.

The Agency's activities in relation to pollution control and waste management will be affected in so far as these functions respond to mitigation policies to limit emissions of greenhouse gases.

The next section provides an overview of the political context for climate change response actions.

3 RESPONDING TO CLIMATE CHANGE

3.1 CONTEXT

The UK's programme of activities to limit emissions of greenhouse gases is being developed in the context of the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol.

The UNFCCC and the Kyoto Protocol are the result of a process that began in 1988 when the United Nations General Assembly resolved to protect the global climate for future generations. At the General Assembly's instructions, the UN Environment Programme (UNEP) and the World Meteorological Organisation (WMO) established the Inter-governmental Panel on Climate Change (IPCC). The IPCC was divided into working groups concerned with the science of climate change, impacts and response options. The IPCC first reported in 1990 concluding that human-induced climate change is a real threat.

In that same year, in response to the IPCC report and growing international concern, the United Nations General Assembly established the Intergovernmental Negotiating Committee (INC) for a Framework Convention on Climate Change.

The UNFCCC was signed by 155 countries at the UN Conference on Environment and Development (UNCED or the Earth Summit) at Rio in June 1992. The Convention came into force on 21 March 1994, 90 days after its ratification by the first 50 countries.

3.1.1 The Objective of the UNFCCC

The ultimate objective of the UNFCCC is set out in Article 2. It is to achieve:

> *stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*

The level of anthropogenic interference or the level of greenhouse gas concentrations that are considered dangerous has not yet been defined.

A number of analysts have suggested that the goal should be to limit atmospheric concentrations of carbon dioxide (CO_2) to levels in the range of 450 to 550 parts per million (ppm). This compares with a pre-industrial (pre-1750) concentration of 280 ppm and a current concentration of approximately 360 ppm. The EC has proposed a long term goal of 550ppm.

3.1.2 *Commitments under the UNFCCC*

The preamble to the Convention notes that

> *the largest share of historical and current global emissions of greenhouse gases has originated in developed countries, that per capita emissions in developing countries are still relatively low and that the share of global emissions originating in developing countries will grow to meet their social and development needs.*

Accordingly, the UNFCCC divides countries into two main groups:

- Annex I parties which are made up of Organisation of Economic Co-operation and Development (OECD) countries and the countries in the process of transition towards a market economy or Economies in Transition (EITs).[(1)] Annex I also includes the European Community which has signed and ratified the Convention separately from, and in addition to, its Member States.

- Non-Annex I countries, which are the developing countries.

There are separate commitments under the Convention for these two different groups.

- All have commitments to report inventories of greenhouse gases, introduce policy measures, support research and promote public awareness of climate change.

- Annex I parties have specific commitments to an emissions target set out in Articles 4.2(a) and 4.2(b) of the Convention. This is generally interpreted as requiring emissions of CO_2 and other greenhouse gases to be returned to 1990 levels by the year 2000.[(2)]

Annex I parties were required to submit national communications containing information about policies and measures and including projections of their emissions. The UK is one of the few countries that is expected to meet its commitment to return emissions to 1990 levels.

(1) Belarus, Bulgaria, Czechoslovakia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Russian Federation, Ukraine (the Czech and Slovak Republics have applied to be recognised as separate parties).
(2) In fact the wording is complex and spread over two paragraphs. The commitments in Articles 4.2(a) and 4.2(b) are for a country to communicate information on its policies and measures introduced with the aim of returning emissions to 1990 levels by the end of the present decade.

3.2 *THE KYOTO PROTOCOL*

3.2.1 *The Negotiations Process*

The Berlin Mandate process, *see Annex C,* was completed before the 3rd Conference of the Parties (COP III) which was held in Kyoto, Japan in December 1997 at which time the Kyoto Protocol was agreed.

The negotiations and the stance of the different countries leading up to Kyoto needs to be seen in the context of very different emissions profiles, projected growth and costs of emission limitations amongst the parties.

- The EU as a block is expected to be close to achieving its emission target for CO_2 by 2000, although emissions are expected to rise after then. Within the EU there are substantial differences in emissions profiles with rates rising very rapidly particularly in the Cohesion countries (Greece, Ireland, Portugal, Spain) offset by falling emission rates in Germany (following unification and industrial collapse in the East), Luxembourg (restructuring of the steel industry) and the UK ("dash to gas").

- In the non-EU OECD countries, loosely grouped together under the JUSCANZ (1) banner, emission rates to 2000 are rising in all cases and are expected to continue to do so in the absence of additional policies.

- Economies In Transition (EIT's) have had emission rates which have fallen substantially since 1990 but which will rise again as their economies grow.

Box C.1, Annex C summarises the main points of the Kyoto Protocol. The most significant aspects of the Protocol are that it continues the split between developed and developing countries and introduces new quantified emission limitation and reduction commitments, which will result in emission reductions for the developed world. However, there are a number of details relating to emissions trading and the inclusion of absorption by sinks, which complicate the assessment of what the aggregate level of emission reductions will actually be.

3.2.2 *Targets and Timetables*

Negotiations on quantified emission limitation or reduction commitments (targets and timetables) focused on three issues:

- gases to be included;
- target levels;
- budget periods.

(1) The original membership was Japan, US, Canada, Australia and New Zealand but it has been extended to include Iceland, Norway, Switzerland and Mexico

The EU has agreed to meet the target jointly. The member states have agreed a burden sharing arrangement which would achieve an 8% reduction in aggregate emissions of the six gases: CO_2, methane (CH_4), nitrous oxides (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6), *see Annex C*. The UK has agreed to reduce its emissions by 12.5% below 1990 levels. The US has a 7% emissions reduction target. See A*nnex C* for a comprehensive overview of all emissions targets and gases included.

In addition to the commitments included in the Convention and the Kyoto Protocol, the current UK government has introduced a domestic objective of reducing emissions of CO_2 to 20% below 1990 levels by 2010.

Commitment Periods

Discussions over commitment periods are closely linked to those on trading as targets are required for more than one year in order to ensure that a trading market can develop. There is considerable discussion over the need for early progress, i.e. by 2005. The commitment period for targets is 2008-2012. This means that the average annual emissions within this period must be at, or below, the targeted level. In addition, Parties must have made demonstrable progress by 2005 towards achieving their commitments under the Protocol.

Absorption by Sinks

Under the Kyoto Protocol, absorption by sinks is not included in the 1990 emission estimates that are used to calculate each party's assigned amount. Only countries that were net emitters from land use change and forestry in 1990 (for example, Australia), will be allowed to include the emissions in their base year emissions estimates. Net emissions or net absorptions from land use change and forestry from January 1st 1990 onwards can be used to offset emissions. Net changes in reforestation, afforestation and deforestation will be counted on the basis of changes in stocks of forests. Parties have not yet defined the scope of these terms, and nor whether additional sink categories could be included. An IPCC special report on sinks is scheduled to be completed in 2000.

The significance of inclusion of sinks is uncertain at this stage but it may allow a number of countries a significantly increased emissions rate relative to that included in their target.

3.2.3 Policies and Measures

Prior to Kyoto, the EU had put considerable effort into analysis of policies and measures that might be included in the Protocol. The work was undertaken by an ad-hoc group focusing on policies that might be adopted as common or co-ordinated measures.

The Kyoto Protocol includes a list of measures that countries might adopt, taking account of their national circumstances without any compulsion to any of them.

The Kyoto Protocol also specifies that Annex I Parties shall pursue limitation of emissions of greenhouse gases from aviation and marine bunker fuels (which are excluded from national targets) working through the International Civil Aviation Organisation and the International Maritime Organisation.

3.3 *COMMITMENTS IN THE LONGER TERM*

Greenhouse gases are generally long-lived in the atmosphere (for example, CO_2 lasts for more than 100 years compared with a few days in the case of sulphur dioxide) so that any emission rate above pre-industrial rates will lead to a build-up in the atmosphere. Stabilising atmospheric concentrations requires reductions in emissions below current rates. For example, to stabilise concentrations at 450 ppm would require global emission rates to be reduced to 1990 levels within 40 years and to drop substantially below 1990 levels subsequently.

Stabilisation of emissions at current levels will not stabilise concentrations by 2100: they will reach about 500 ppmv by 2100, rising slowly for several hundred years , against a current concentration of 360 ppmv and a Business As Usual concentration of 750 ppmv. A safe emissions corridor, compatible with the ultimate UNFCCC objectives ‘to allow ecosystems to adapt naturally to climate change’ and ‘to ensure that food production is not threatened’ while allowing ‘economic development to proceed in a sustainable manner’ would be a range of 78- 127% of 1990 emissions by 2100, requiring a 15% reduction on 1990 levels. *See annex A* for a full treatment of emission corridors.

Commitments under the Convention and the Protocol are regarded as initial steps towards the achievement of the ultimate objective. The limitations to the current commitments include the fact that there are no quantified emission limits for developing countries, which are becoming an increasingly significant source of total emissions. The aggregate emission reductions committed to by developed countries will be far outweighed by the increases in the developing world.

A number of analysts have sought to explore the relationship between eventual requirements of the climate change agenda and national emission targets.

3.4 *THE RANGE OF POSSIBLE RESPONSES*

The UK response to climate change includes:

- climate science - the UK is at the forefront of scientific activity that is developing a better understanding of the causes of climate change and the likely rate and magnitude of future changes. Modelling work from the Hadley Centre is sponsored by the DETR;

- information collection including emission inventories and the development of indicators of climate change;

- limiting emission rates in the context of the UNFCCC, explored in *Section 6;*

- understanding the impacts of climate change and the adaptation requirements, explored in *Section 5 and 7.*

The Agency has the potential to participate in the national response to climate change in ways that include:

- responses consistent with its statutory duties. This will include measures to reduce emissions from the facilities it licences and measures to adapt to likely changes in climate, thus limiting the risks of climate change for the environmental resources the Agency manages;

- contributions to the national climate change response which go beyond these statutory duties.

The remainder of this section explores the first two areas of work. *Sections 6 and 7* examine options relating to emission limitation policy (mitigation) and adaptation.

3.4.1 Climate Science

The main UK activities relating to climate science are coordinated and carried out by the Hadley Centre for Climate Prediction and Research, jointly funded by the DETR and the Meteorological Office. The main objective of the Hadley Centre is to provide, for the UK Government, an authoritative, up-to-date assessment of both natural and human-induced climate change.

The main aspects of the research programme are:

- to simulate the present climate and understand its natural variability;

- to understand the factors controlling climate change and to predict global and regional climate change up to the end of the 21st century;

- to develop and use global climate models to support the above tasks;

- to provide a focus for both national research programmes relevant to climate change prediction and for interaction with international programmes. Results from these programmes are incorporated into the prediction models.

3.4.2 Information Collection

National Inventories

The UK's commitments under UNFCCC include a commitment to:

> *Develop, periodically update, publish and make available ….. national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases* (Article 4.1(a)).

The UK's national inventory is produced for the DETR in accordance with guidelines for emission inventories by IPCC and agreed by the Conference of the Parties to the UNFCCC. National greenhouse gas inventories are produced annually and cover the six gases included in the Kyoto Protocol. The UK inventory, in addition, provides data on nitrogen oxides (NOx), Carbon monoxide (CO) and Volatile Organic Compounds (VOCs). Inventories sort data by source under the following categories:

- energy and transformation - emissions from the combustion, transfer, storage and processing of energy fuels;
- industrial process emissions, eg from the production of cement;
- solvents;
- agriculture;
- land use change and forestry;
- waste.

One component of the UK inventory is the Inventory of Sources and Releases (ISR), produced by the Agency, which gives information on releases on land, air and water from industrial processes covered by IPC. Experience and feedback on the collection, validation and review of data during 1999 will help inform the development of the ISR for future years.

In addition, interest in 'green reporting' is growing in the private sector. A set of guidelines has been produced by the Global Reporting Initiative (GRI) for comparison of environmental, social and the financial performance of companies to date.(1) Green indicators include total consumption of energy materials and emissions.

(1) ENDS Daily - 03/03/99

The details of current emissions and recent trends are provided in *Section 4.5.*

Indicators of Climate Change

Currently the detection of climate change is achieved through:

- modelling, particularly as models have become better at reproducing current climate - the success of recent modelling experiments has enabled scientists to state that the balance of evidence suggest a discernible human influence on global climate;

- trends, particularly the frequency of climate anomalies.

Another approach is through the use of indicators, ie the identification of a number of factors that can be monitored over time and, through comparison with expected outcomes or historical trends, can be used to identify an emerging trend. The DETR recently has funded research work to develop a number of indicators of climate change.

The Agency might be well placed either to contribute towards the development of this indicator programme or to develop its own on the basis of some alternative set of indicators.

4 *CLIMATE CHANGE PROJECTIONS*

4.1 *CLIMATE CHANGE 'THE ISSUE'*

4.1.1 *An Enhanced Greenhouse Effect*

The Earth absorbs radiation from the Sun. The Earth's surface is warmed by this absorbed radiation and emits radiation at longer wavelengths. On average, the incoming solar energy is balanced by outgoing radiation. Some of the long-wave radiation is absorbed and then re-emitted by a number of trace gases resulting in a positive radiative forcing which warms the lower atmosphere and surface. This is known as the 'greenhouse effect' and the trace gases which produce this effect are known as greenhouse gases. The greenhouse effect is a natural phenomenon without which the Earth's surface would be approximately 33°C cooler than it is at present.

Human activities, however, have led to increasing concentrations of greenhouse gases in the atmosphere which leads to an enhanced greenhouse effect. Naturally occurring greenhouse gases are water vapour (by far the most important), CO_2, CH_4, N_2O and tropospheric ozone (O_3). Hydrochlorofluorocarbons (HCFCs and other synthetic greenhouse gases such as chloroflurocarbons (CFCs), HFCs, PFCs and SF_6) also act as greenhouse gases but result only from human activities. Concentrations of CO_2, CH_4 and N_2O have increased by about 30%, 145% and 15% respectively, since pre-industrial times (roughly 1750). The concentration of CFCs has peaked, but the concentration of HCFCs has not peaked yet.

Any changes in the radiative balance of the Earth, whether due to human-induced increased concentrations of greenhouse gases, or naturally occurring fluctuations in output from the Sun or volcanic eruptions, will tend to alter atmospheric and oceanic temperatures and the associated circulation and weather patterns. These changes will be accompanied by changes in the distribution and amount of clouds, precipitation and evaporation. Therefore climate is expected to change in the future and, indeed, is likely already to have responded to the observed increase in concentration of greenhouse gases in the atmosphere. The concentration of water vapour in the atmosphere is not directly affected by human activities but is determined within the climate system. Increased surface temperatures are likely to lead to a more vigorous hydrological cycle and an increase in atmospheric water vapour, possibly leading to a further enhancing of the 'greenhouse effect'. Tropospheric aerosols (small particles) derived mainly from the emission of sulphur dioxide from fossil fuel burning can absorb and reflect solar radiation. They generally produce a negative radiative forcing and contribute to a relative lowering of surface temperature.

Current estimates of future climate change from IPCC are in the region of a 2°C increase in global-mean temperature and a 50cm increase in sea level by the year 2100.[1] Associated with this increase in temperature will be changes in other aspects of climate such as precipitation, evaporation, circulation patterns and, possibly, the frequency of extreme events.

4.1.2 *Detection of Climate Change*

Although the average temperature of the Earth's surface has risen by 0.6°C since the mid-19th century, it can be argued that such a change might be natural. Attempts to relate part of the recent changes in global climate to anthropogenic influences are referred to as detection. Detection efforts have sought to show that the observed pattern of temperature rise is in accord with that produced by computer model simulations. From the first attempts[2] to more recent ones,[3] there had been little success. The situation changed with the latest GCM integrations which included both the warming effects of increasing greenhouse gases and the more regionally specific cooling effects resulting from the release of additional pollutants from fossil fuel burning which produce atmospheric sulphate aerosols. Detection exercises with these new integrations do show an increasing convergence of the model changes in temperature with observed change, both at the surface [4] and in the free atmosphere.[5] The increases have been shown to be statistically significant when compared with model-based estimation of natural variability on the decadal-to-century timescale. These results led the IPCC in 1995 to state '*... the balance of evidence suggests a discernible human influence on global climate*'.

4.2 *MODELLING FUTURE CLIMATE CHANGE*

GCMs represent the most sophisticated method currently available for estimating the future effects of increasing greenhouse gas concentrations on climate. The increase in computing power in recent years has led to a dramatic improvement in the scope and ability to simulate the climate system. These changes have resulted in higher resolution capability in the GCMs, the production of improved simulations of the present climate and the ability to model a transient future climate.

The results of recent modelling work is described in more detail in *Annex A*. The broad thrust of these results is outlined in *Box 4.1*.

(1)Houghton, J.R., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. and Maskell, K.(eds.), 1996 *Climate Change 1996: The Science of Climate Change*, Cambridge University Press, Cambridge 572pp.

(2)Barnett, T.P. and Schlesinger, M.E., 1987 *Detecting changes in global climate induced by greenhouse gases.* J. Geophys. Res. 92, 14772-14780.

(3)Santer, B.D., Wigley, T.M.L. and Jones, P.D., 1993 *Correlation methods in fingerprint detection studies.* Climate Dynamics 9, 267-285.

(4)Santer, B.D., Taylor, K.E., Penner, J.E., Wigley, T.M.L., Jones, P.D. and Cubasch, U., 1995 *Towards the detection and attribution of an anthropogenic effect on climate.* Climate Dynamics 12, 77-100.

(5)Santer, B.D., Taylor, K.E., Wigley, T.M.L., Johns, T.C., Jones, P.D., Karoly, D.J., Mitchell, J.F.B., Oort, A.H., Penner, J.E., Ramaswamy, V., Schwarzkopf, M.D., Stouffer, R.J. and Tetts, S., *1996 A search for human influences on the thermal structure of the atmosphere.* Nature, 382, 39-46.

Box 4.1 ***A summary of the hemispheric/continental scale changes in future climate simulated by GCM experiments (taken from Houghton et al., 1996)***.

- All experiments, with and without sulphate aerosols, show greater surface warming of the land than of the sea in winter, a maximum surface warming in high northern latitudes in winter, an enhanced global mean hydrological cycle and increased precipitation and soil moisture in high latitudes in winter.
- Most experiments show a reduction in the strength of the North Atlantic thermohaline circulation and a widespread reduction in diurnal range of temperature.
- Aerosols tend to reduce the magnitude of temperature and precipitation changes, however, the effect is not a simple offset of the effects of increased greenhouse gases. The spatial distribution of aerosols has a strong influence on regional patterns of climate change.
- Warmer temperatures will lead to a more vigorous hydrological cycle. Knowledge is currently insufficient to determine whether there will be any changes in the frequency and spatial distribution of severe storms.

Despite agreement between GCM results, large uncertainties remain in the estimation of future emissions and concentrations of greenhouse gases, rates of biogeochemical cycling and the feed-backs associated with clouds, oceans, sea ice and vegetation.

There are also uncertainties in making projections at regional scales. GCM resolutions, though improved, are still too coarse and there is naturally greater variation in local climate than in climate averaged over larger scales. Because of this uncertainty, regional changes in climate derived from GCM experiments are termed scenarios or projections and cannot be considered predictions. Nonetheless, they provide a framework from which the potential magnitude and nature of future climate change and its impacts can be assessed.

4.3 *SCENARIOS OF CLIMATE CHANGE IN THE UK*

A set of scenarios of climate change in the UK have been produced by CRU, as a component of the UKCIP. The UKCIP aims to develop an integrated assessment of the impacts of climate change in the UK. The scenarios have been produced in order to assist impact researchers and to ensure consistency of assumptions in analysis.

There are four scenarios: low, medium-low, medium-high and high. They are based on Hadley Centre HADCM2 model runs and include differences in:

- forcing - the annual increase in CO_2 equivalent concentrations;
- an increase in mean temperature associated with a doubling in CO_2 concentrations.

The effects of these scenarios on the global mean values for changes in temperature and precipitation are given in *Figures 4.1 and 4.2*.

In general England and Wales are expected to get warmer and wetter. The south of England is expected to warm more than the north whereas the north is expected to get wetter than the south. The changes in temperature show marked seasonal differences. Specifically, increases are greater in the winter than in the summer. The seasonal difference is even more marked for precipitation. Winter precipitation increases everywhere but decreases in the summer.

Figure 4.1 ***Change in average annual temperature (Celsius)***

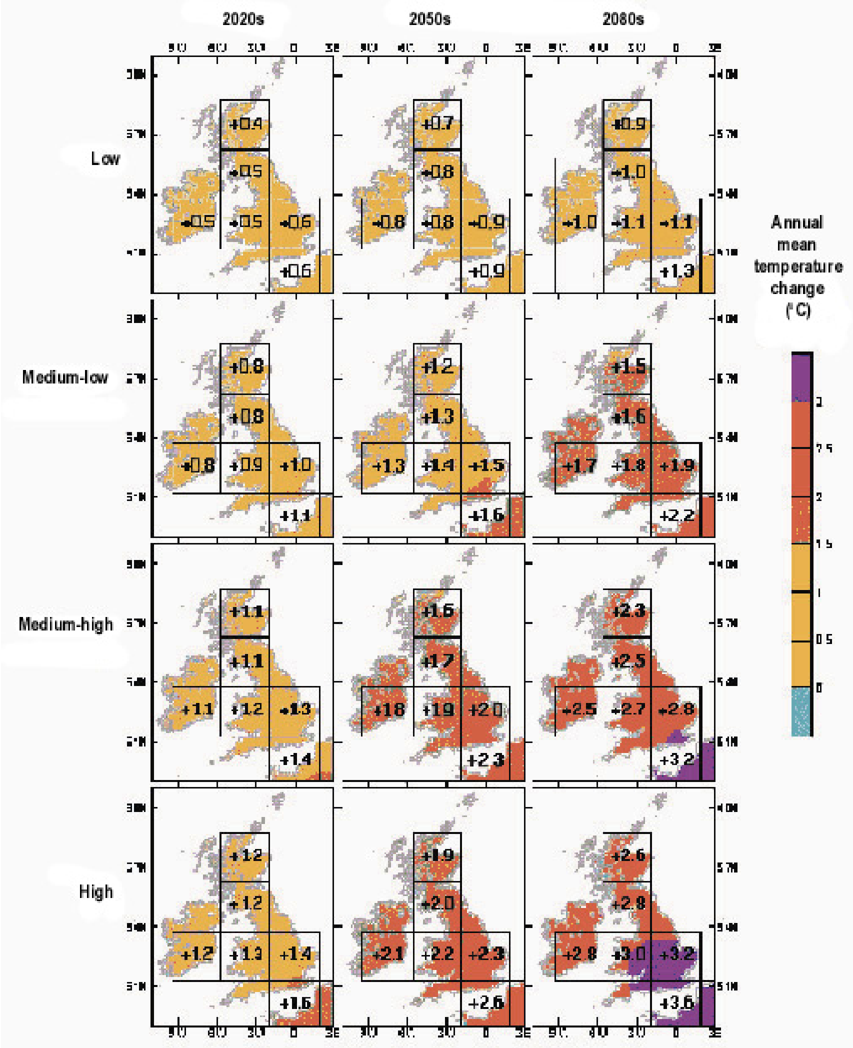
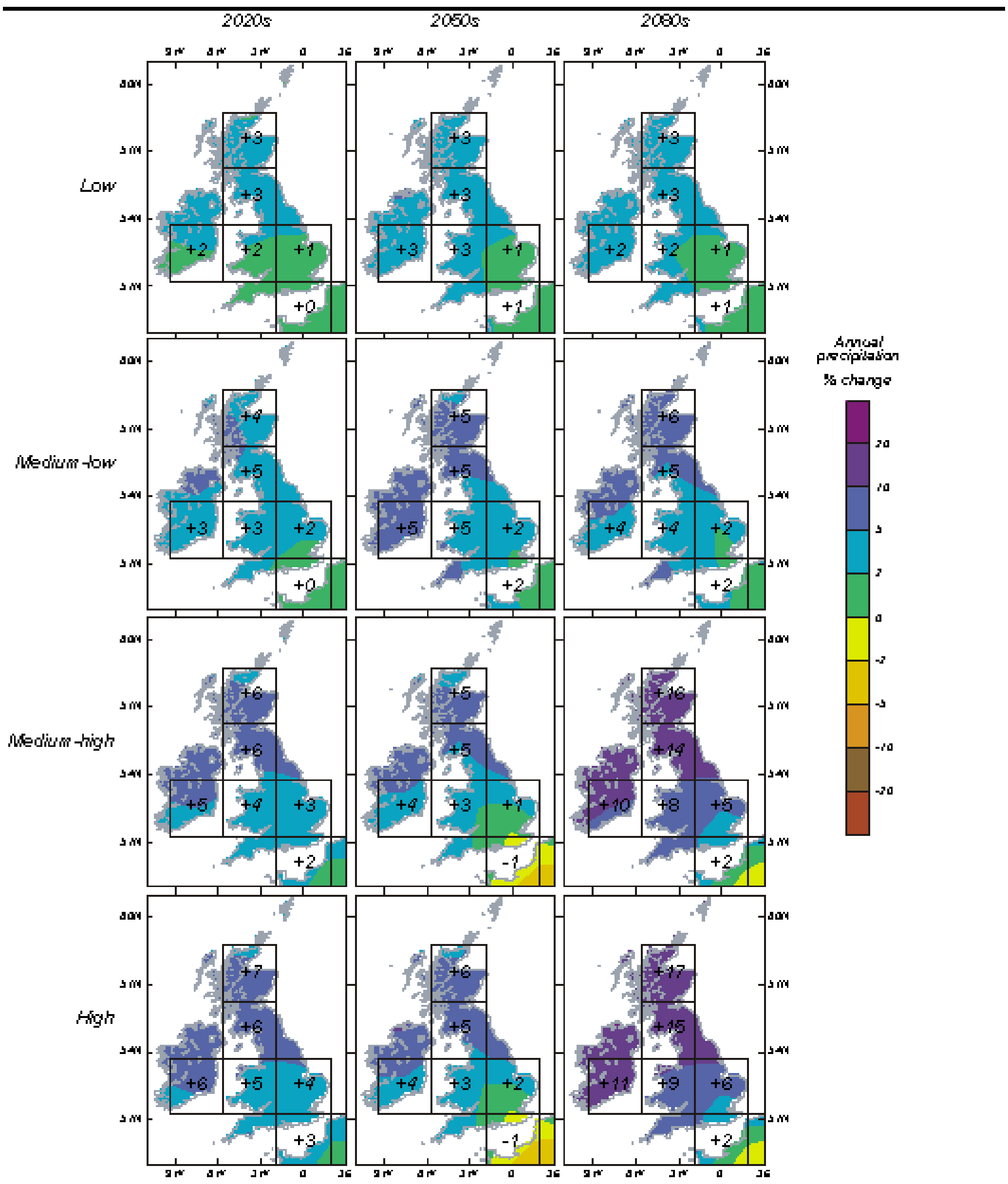


Figure 4.2 Change in average annual precipitation



4.4 SUMMARY OF EXPECTED CLIMATIC CHANGES FOR THE UK

New climate scenarios and recent impacts assessments update those contained in the report to the NRA by Arnell et al. (1) There are no major differences in the findings now and in 1994. Future climate scenarios presented here show broadly similar changes in temperature and precipitation to the scenario in the Climate Change Impacts Review Group (CCIRG, 1996) which came from an earlier version of the GCM used by the Hadley Centre. In summary, the changes suggest the following.

(1)Arnell, N.W., Jenkins, A. & George, D.G., 1994, *The implications of climate change for the National Rivers Authority.* Final Report (R&D Report 12) to the National Rivers Authority. HMSO, London, 94pp

- A warming, compared with the 1961-90 average, of between 1.3°C and 3.6°C by the 2080s over Southeast England and 1.0°C - 2.8°C over Northwest England. The warming is slightly more accentuated in the winter than in the summer and is greater in night-time than day-time.

- Annual precipitation increases of 1-2% in Southeast England by the 2080s and increases of 2-9% in Wales and 3-15% in the Northwest. There is a marked difference in seasonal precipitation changes with a 6-23% increase in winter precipitation in Southeast England compared with a 8-27% reduction in summer precipitation for this same region. There will thus be a slight steepening in the north-south precipitation gradient and an enhancement of the winter-summer precipitation contrast over the British Isles.

- A decrease in the number of rain-days but an increase in the intensity of precipitation on rain-days.

- No major change in circulation patterns over the region.

Section 5 explores the expected impacts of these changes on a range of natural environments and other activities of the Agency. In addition, *Annex B* provides further information regarding the hydrological and air pollution impacts of recent climate variability in the UK. Some of the recent anomalies are consistent with expectations of future climate and provide a useful pointer towards likely future climates.

4.5 CURRENT EMISSION RATES AND PROJECTIONS

Within the UK, policy makers are concerned about emissions at different levels:

- at the national level, because this determines the UK's responsibility for limiting emissions within the context of national targets and internationally agreed quantified emission limitation and reduction commitments;

- at the EU level because the UK's responsibilities are being developed in the context of a commitment and assigned amount which applies to the EU as a whole;

- amongst developed countries, ie those that have been given quantified emission limitation and reduction commitments and assigned amounts under the Kyoto Protocol; and

- at the global level as global emissions and atmospheric concentrations determine what the overall level of impact of greenhouse gases will be on the UK.

4.5.1 *National Emission Rates*

The UK's emissions levels are quantified in the national inventory [(1)] produced for the DETR.

Emissions of the six greenhouse gases introduced under the Kyoto Protocol can be compared on the basis of Global Warming Potentials (GWPs) which measure the relative radiative effects of the gases compared to CO_2. The GWP concept has been developed for relatively long-lived gases for which there is even mixing in the atmosphere and the warming effect is truly global. GWPs are not applicable to gases and aerosols that are unevenly distributed in the atmosphere; these include NOx, CO and Non-Methane VOC (NMVOC) which are precursors of another greenhouse gas, ozone.

CO_2 makes up 81.3% of total UK greenhouse gas emissions and the major source of CO_2 is fossil fuel combustion for energy purposes.

The UK is above the EU average for CO_2 emissions per capita but less than the OECD average per capita which is dominated by the high emission rates in the US. *See Annex A* for further details. UK methane and nitrous oxide emissions per capita are close to OECD and EU averages.

4.5.2 *Emissions from Sites Licensed by the Agency*

The Agency is responsible for licensing or permitting a range of sites which are responsible for emissions of greenhouse gases. These include:

- power plants and other large industrial users of energy and thus producers of energy-related greenhouse gases;
- emitters of CO_2 from industrial (IPPC) processes and of other greenhouse gases;
- landfills and incinerators.

It is difficult to estimate the proportion of total emissions coming from IPPC processes accurately, as emission inventories do not categorise industrial sectors in a way that enables licensed sectors to be identified. However, IPPC emissions are dominated by energy and transformation industries, particularly power plants. Taking into account emissions occurring under IPPC, emissions from waste and a proportion of emissions from industrial energy and processes, it is apparent that the Agency is responsible for licensing sites emitting approximately 45% of UK CO_2 emissions and a similar percentage of the aggregate of the six greenhouse gases.

(1) Salway AG (1997) UK Greenhouse Gas Emission Inventory, 1990 to 1995. National Environmental Technology Centre.

4.6 *EMISSION LEVELS AND DRIVING FORCES*

This section looks at current emission levels, the causes of greenhouse gas emissions, their drivers and the issues that the Agency needs to consider under its Environmental Strategy.

The driving forces for carbon dioxide emissions include:

- demand for energy in all its forms by industrial, commercial and household sectors;
- shifts in the mix of energy fuels;
- demand for transport.

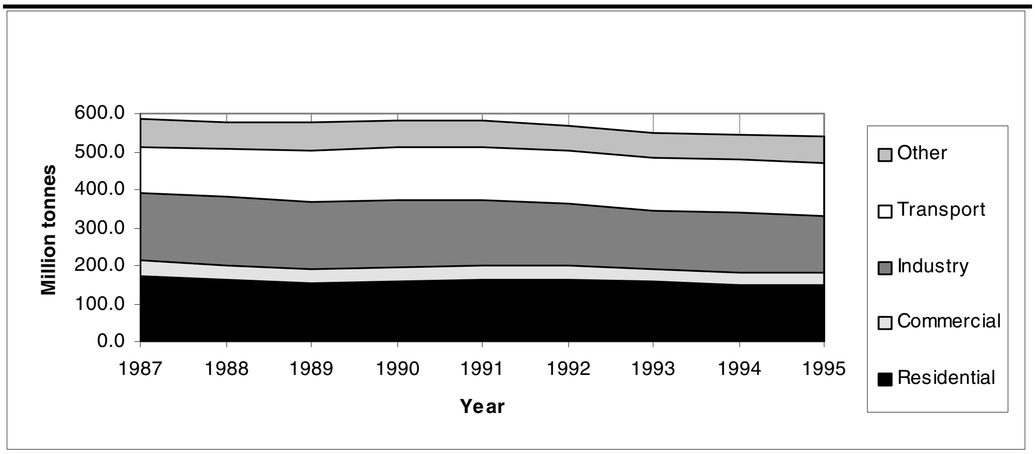
The main drivers for methane and nitrous oxide emissions are industrial and agricultural activity.

4.6.1 *Carbon Dioxide*

CO_2 accounts for 81% of the warming potential of the UKs greenhouse gas emissions. Since 1990, CO_2 emissions have fallen by 7%, this being accounted for almost wholly by reductions in emissions from the power sector. In this sector there has been a small increase (4%) in electricity output but a large decrease (19%) in emissions because of fuel switching from coal to gas, the increasing contribution of nuclear power and general improvements in the efficiency of power stations.

Figure 4.2 shows CO_2 emissions by end user, allocating emissions from electricity to the users of the electricity. The relative contribution of each sector has not changed significantly over time, with emissions relatively evenly split amongst the main sectors, residential (27% in 1995), industry (28%) and transport (26%).

Figure 4.3 CO_2 Emissions by End User



Digest of Environmental Statistics 1997

Road transport is the fastest source of growth of emissions of CO_2, and the only major sector for which emissions are forecast to grow by 2000. Petrol use has decreased by 10% since 1990 but diesel use has increased.

Industrial energy demand fell by 5% in the period 1990 to 1995 whilst CO_2 emissions from industrial combustion decreased by 9% from 1990 to 1995. The additional reduction in emissions is due to fuel switching from coal and oil to natural gas.

The small combustion sector made up of residential and commercial/institutional users has increased since 1990 by 3% overall. Residential emissions have increased by 1.3%. Emissions from the commercial/institutional sector have increased by about 8%.

Demand for energy

The main developments in the demand for energy in the UK are:

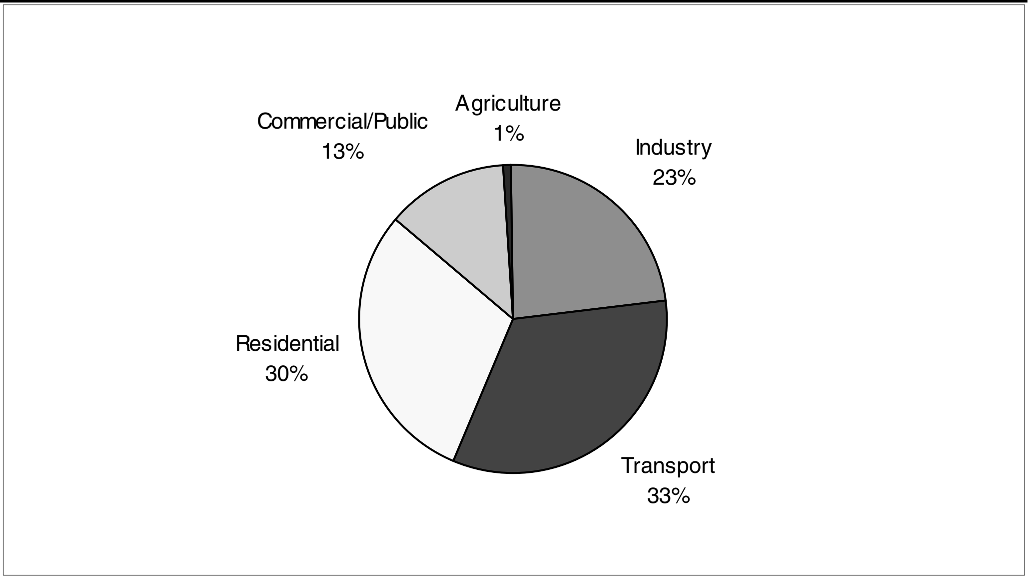
- increased energy demand per capita due to increased per capita income;
- increased population;
- energy price reductions from deregulation of energy markets and falling oil prices.

All of these factors will tend to increase overall levels of demand. These will be offset by:

- energy efficiency improvements from technological change and conservation measures;
- structural shifts in the economy towards less energy intensive sectors.

The sources of current energy demand, by end user, are shown in *Figure 4.3.* The main sources of demand are the residential and transport sectors, neither of which the Agency has any regulatory or other control over. The Agency has a potential role with respect to industrial energy.

Figure 4.4 Energy Consumption by Final User (1996)



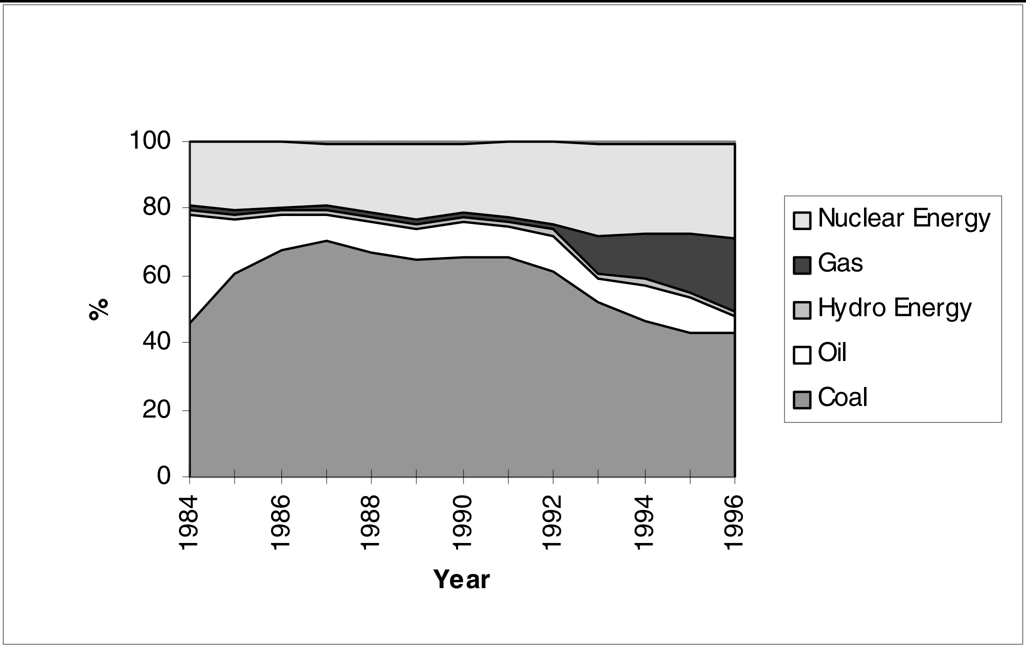
Digest of Energy Statistics 1997

Fuel Mix

Changes in fuel mix, particularly for electricity generation, have been a very significant component of changes to UK greenhouse gas emissions in recent years (see *Figure 4.4*). Natural gas contributed approximately 1% towards total fuel supply for electricity generation in 1990 but is expected to contribute 38% by 2000, although the impacts of the recent gas moratorium may limit this shift. Currently gas contributes more than 20% of total fuel supplies.

Renewable energy currently constitutes a small percentage of total electricity generation and is dominated by hydro power. The government is investigating the potential for achieving a 10% contribution of renewables by 2010. Nuclear power currently contributes approximately 30% to total electricity generation. Nuclear will continue to be used for the foreseeable future, provided high standards of safety and environmental protection are maintained. However, the government position on the longer term role of nuclear power is unclear. A reduced contribution of nuclear power to power generation will make greenhouse gas emission reduction more difficult.

Figure 4.5 Fuel Use in Electricity Generation



Digest of Energy Statistics 1997

Demand for Transport

One of the main contributors to emission changes is the transport sector. Vehicle kilometres increased by 36% in 1986-96 and are expected to increase by 25-40% from 1996 to 2010.(1) Tonne kilometres of road freight are also expected to rise by 30-54% by 2010 compared to 1996.

4.6.2 Methane

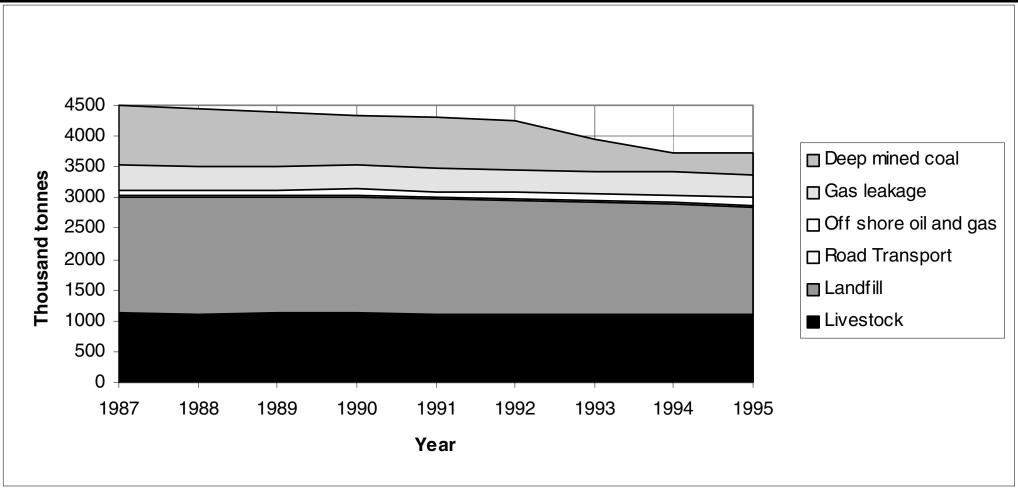
Methane contributed to 12% of the global warming potential from national greenhouse gas emissions in the UK in 1990. Major sources of methane emissions are landfill sites (46%), livestock (29%), production and distribution of fossil fuels (22%) and leakage from the gas distribution system. Only 2% comes from fossil fuel combustion. Natural sources of methane derive from anaerobic breakdown of biological matter, for example peat-bogs and wetlands.

Total UK methane emissions have fallen by around 14.5% since 1990. Methane emissions are expected to continue to fall until 2000, a reduction of 22% on 1990 levels, primarily because of a reduction in coal mining and waste going to landfill. There will be some additional emissions as a result of the EC Urban Waste Water Treatment Directive and the associated increase in sewage sludge. The rate of increase will depend on the disposal route adopted.

(1) Department of the Environment, Transport and the Regions (1997) Transport Statistics Great Britain.

Landfilling continues to be the most widely used method of waste disposal, accounting for around 83% of municipal wastes. There has been a decrease of 7% in methane emissions from this source because of the increased use of methane recovery systems. This trend will continue as all new landfill sites are required to have gas recovery systems, and all existing landfills will have to be retrofitted to include these systems in the future.

Figure 4.6 Methane Emissions by Source



Digest of Environmental Statistics 1997

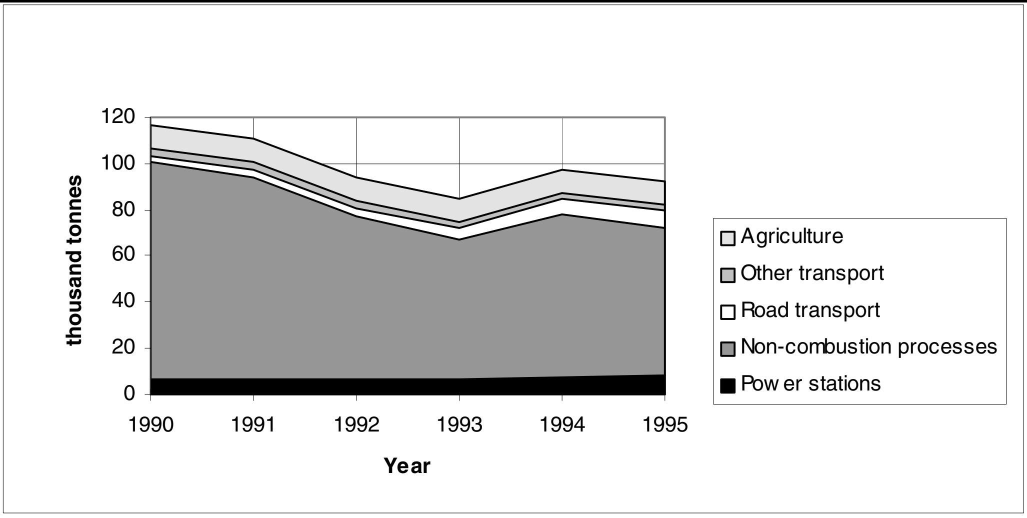
Since 1990, agricultural emissions have fallen by 2.3% largely because of a reduction in dairy cattle numbers. It is expected that cattle numbers will decline leading to decreases in UK emissions of methane emissions between 1990 and 2000. This is partly due to the reform of the Common Agricultural Policy (CAP) and gradual improvements in cattle productivity.

Leakages from the natural gas distribution network amount to 9% of total methane emissions. A leakage control strategy aims to reduce emissions from the transmission network by 20% on 1992 levels by 2000.

4.6.3 ***Nitrous Oxides***

Emissions of nitrous oxides are uncertain because there are many small sources, both natural and man-made. Detailed emissions data are not yet available. Adipic acid manufacture (for the production of nylon) and the production of nitric acid are the two major emitters. N_2O emission from adipic acid manufacture, the largest single source of emissions (72% of 1990 emissions), will be cut by a minimum of 95% through a change in the technological processes used by DuPont Ltd.

Figure 4.7 Nitrous Oxide Emissions by Source



The other significant source is from agriculture in which emissions have stayed relatively constant. These emissions arise from agricultural soils and manure management.

Part of the reform of the CAP is the extensification of agriculture, ie a non-rotational set-aside scheme, under which most farmers must set aside a percentage of their arable land. The removal of land from agricultural production, as well as the general decline in financial support by the EU for many agricultural commodities is expected to reduce the use of chemical fertilisers and emissions of N_2O. The expansion of agri-environment schemes also encourage reduced fertiliser use. For example, all land managed under the Environmentally Sensitive Areas Scheme must receive low rates of organic and inorganic fertiliser.

4.6.4 *Other Greenhouse Gases*

Emissions of HFCs come from the manufacture of fluids, from their use in various appliances and from fugitive losses during chemical production processes. UK emissions of HFCs are anticipated to increase between 1990 and 2000 mainly as a result of their increased usage as replacements for ozone depleting substances. A stated aim of the UK Climate Change Programme is that any actions taken to reduce HFC emissions should not damage current efforts to phase out ozone depleting substances. Voluntary agreements with some HFC using sectors set out strategies to minimise emissions of HFCs and to ensure that they are only used if safer and practical alternatives do not exist.

PFCs are emitted from aluminium smelting, the foam blowing and electronics and electrical sectors and during fluid manufacturing processes. They are also being considered for future uses in the fire-fighting and solvent sectors. PFCs are prescribed substances under the IPPC regulation. Emissions of PFCs are expected to decrease between 1990 and 2000 largely from emission reduction policies in the aluminium industry.

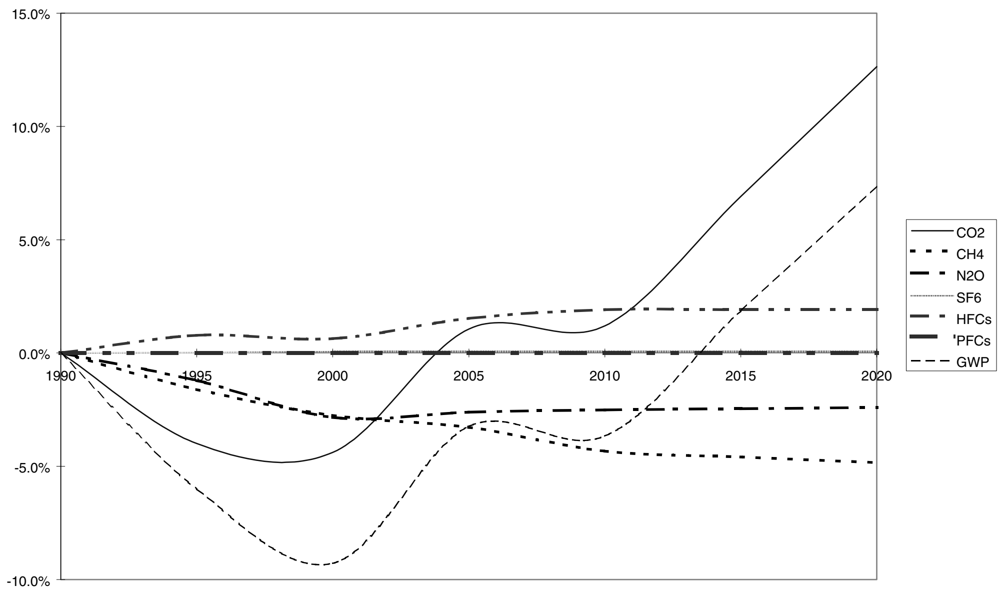
SF_6 is used mainly as a cover gas in the magnesium industry, for electrical insulation in power transmission equipment and in specialised electronic applications. Emissions of SF_6 are anticipated to increase reflecting an anticipated increase in the use of magnesium foundries.

4.7 *UK EMISSION PROJECTIONS*

The UK, along with other Annex I Parties, has a responsibility to report on projections of emissions in its national communication. Projections of greenhouse gas emissions are included in the UK's Second National Communication under the UNFCCC.

Figure 4.7 shows the importance of the different gases to the future growth in emissions, under a Business As Usual scenario. It graphs the percentage increase in individual and aggregate emissions of six greenhouse gases as a percentage of 1990 emissions.

Figure 4.8 Growth in UK Emissions of Six Greenhouse Gases



The overall trends in greenhouse gas emissions are dominated by those for CO_2. Emissions in the current period are falling largely in response to the impact of fuel switching in the electricity generation sector and reductions in coal and fuel oil use in industry. *See Annex A* for EU and global emissions projections.

5 IMPACTS

5.1 IMPACT ASSESSMENT

Impact assessment has been used to convert the models of climatic change into physical effects on environmental attributes of concern to people. In the UK a number of studies have begun to examine these impacts, often for individual sectors and issues. CCIRG produced a more comprehensive review of the impacts on the UK in 1996. Other relevant studies include a 1994 review of the implications of climate change for the National Rivers Authority (NRA).[(1)] The section below builds on these and other sectoral studies. In 1997 the DETR established the UKCIP in order to develop a more integrated assessment of the impacts of climate change on the UK. Its aim is to encourage and support research that allows for a greater understanding of the interactions amongst different sectoral impact areas.

5.2 IMPACTS ON WATER RESOURCES

5.2.1 The relationship between climate and water resources

Two of the principal and immediate concerns of the Agency relate to management of water resources and delivering integrated river-basin management. The water supplied to consumers in England and Wales originates either from surface sources (natural or artificial reservoirs and rivers) or from sub-surface sources (groundwater aquifers). The water contained in these stores represents what remains from the total precipitation inputs to the system after losses to evaporation (from plant, soil and other surfaces), transpiration (from plant extraction of soil moisture) and any other long-term sinks of water. Water reaching these stores depends on a complex interaction over various space and time scales of:

- climate (the characteristics and magnitude of precipitation and potential evapotranspiration);
- land cover (albedo, interception, stomatal conductance);
- soil (infiltration rate, depth and water holding capacity);
- slope factors (angle aspect).

(1) Arnell NW, Jenkins A and George DG (1994) *The Implications of Climate Change for the National Rivers Authority*. Institute of Hydrology R&D Report 12. HMSO.

Empirical and modelling studies of the catchment water balance show that changes in precipitation are generally the key factor to influence the resulting runoff. Temperature is also an important determinant of summer flows through its role in evapotranspiration.
The uncertainty associated with estimates of future changes in precipitation is much higher than with changes in temperature. Impacts are likely to be:

- changes in precipitation affecting soil moisture, river flows, extreme events such as floods and droughts, reservoir storage, groundwater recharge, water quality, irrigation demand and rainfed agriculture;

- changes in temperature, wind speed, humidity and the nature and distribution of vegetation affecting water availability, runoff and evaporation losses;

- changes in the atmospheric circulation, affecting the frequency, magnitude and patterns of storms and droughts.

5.2.2 Impacts on river Flows

Monthly and annual flows

Recent analyses have aimed to assess the effects of climate change on river flows, *Table B3 in Annex B*, and groundwater recharge, *Table 5.1*. Two broad patterns are apparent:

- there is a decline in mid to late summer flows, which is less pronounced in groundwater dominated catchments;

- there is an increase in winter and a larger increase in spring flows, although this is subject to significant uncertainty.

Daily and extreme flows: floods and low flows

The case studies undertaken so far in the UK have almost all considered the impacts of climate change upon annual and monthly river flows. Changes in the frequencies of extreme events are likely to be equally, if not more, important for managing water resources. It is changes in daily and sub-daily precipitation at the river basin scale that will determine changes in the runoff response for extreme events in the future.

Very little work has dealt with the impacts of climate change on the frequency of extreme events, such as floods and extended periods of low flows, mainly because of the much greater uncertainty associated with climate scenarios at the detailed spatial and temporal scales required for such analyses.
Nevertheless it is highly likely that changes in the mean characteristics of river flows will be accompanied by changes in the frequency of extremes.

Greater precipitation intensities may lead to higher incidence of floods. Catchment responses will also be affected by catchment characteristics and changes in antecedent conditions which may become drier as a result of the reduced numbers of rain days and increases in potential evaporation.

Reduced low flows due to lower summer precipitation and increased potential evaporation will cause higher frequencies of low flow events with consequent implications for the maintenance of water supply and quality. As with changes in flood frequencies, however, the response of river flows to any given change in climate also varies according to catchment characteristics such as the magnitude of their base flow components, physical characteristics and land cover.

Table B3 and B4 in Annex B show percentage changes in streamflow for different regions in the UK and percentage change in monthly run-off for ground water dominated rivers.

5.2.3 Impacts on Groundwater

Groundwater comprises roughly a third of the water supplies in England and Wales. Groundwater recharge is primarily determined by percolation of winter precipitation. It is changes in the length of the period over which recharge occurs, and the total amount of precipitation that will affect groundwater supplies (changes in snow-melt characteristics are particularly important in Scotland). To date, only a few studies have looked at groundwater response to climate change in the UK and elsewhere. Potential increases in recharge due to the increases in winter precipitation suggested by the climate scenarios may be offset by increased losses to evapotranspiration causing a shortening in the length of the recharge season.

Different types of aquifer possess different sensitivities to any given climate change.[(1)] Arnell *et al* [(2)] estimated recharge in groundwater dominated catchments under different climate change scenarios *(Table 5.1*) Results are dependent on the climate model scenarios and the aquifer. For example, recharge in chalk aquifers decreases in the east, whereas it increases in aquifers dominated by Permo-Triassic rock formations.

Table 5.1 Percentage Change in Annual Recharge by the 2020s for England and Wales by Aquifer Type

Climate Model	Chalk (south)	Chalk (east)	Permo-Triassic (west)	Permo-Triassic (east)	Others
HADCM1	-4	-4	-7	2	0
GG1m	15	15	14	7	10
GS1m	10	10	10	4	7
GS1t	-6	-8	-6	0	2

(1) Cooper, D.M., Wilkinson, W.B & Arnell N.W., 1995: *The effects of climate change on aquifer storage and river baseflow*. Hydrological Sciences Journal 40 (5), 615-629

(2) Arnell N., Reynard N., King R., Prudhomme C. and Branson J., 1997 *Effects of climate change on river flows and groundwater recharge; guidelines for resources assessment*. Environment Agency Technical Report No W82

5.2.4 *Impacts on demand*

Climate change is likely to affect both supply and demand. To date, there are only a few existing studies of the relationships between climate variability and the demand for water. Herrington[1] undertook the only major investigation into this issue in a study commissioned by the DoE. (For summary results *see Box B1 in Annex B.*) The results show that climate change may lead to a 4% increase in overall demand by the 2020s. Agricultural irrigation water is particularly sensitive to climate changes.

5.2.5 *Direct effects of CO_2*

The actual concentration of CO_2 in the atmosphere may have direct effects upon the water use efficiency of vegetation. Controlled experiments show that increased concentrations of CO_2 increase the resistance of plant stomata to water vapour transport, thereby reducing transpiration losses for a given leaf area. Increased CO_2 concentrations may also have a fertilisation effect on vegetation. The resulting increase in growth / leaf area may offset increased water use depending on factors such as vegetation type, soil and climate conditions. The net effect upon water supplies is uncertain.[2]

5.3 WATER QUALITY

5.3.1 *Changes in Water Inputs*

Treated sewage effluent

The primary source of pollutants in rivers is sewage treatment works. Treated sewage effluent contributes much of the biochemical oxygen demand (BOD) and the ammonia load which impinges on dissolved oxygen concentrations in rivers. Higher water temperatures increase the rate of biological activity within the stream which would tend to decrease oxygen levels. This effect could be compounded by a decrease in water levels. However, water quality may improve given the fact that sewage treatment works are more efficient at higher temperatures as treatment processes work faster.

Leaching of agrochemicals

Natural drainage systems, through which pollutants enter the aquatic environment, currently pose many problems for water quality. Uncertainty surrounds the issue of how precipitation affects the rate of pollutants entering water courses. Generally, the lower the flows, the higher the concentration of pollutants. However, leaching may complicate this relationship. Low flows may reduce leaching thus posing few problems for water quality. However,

(1) Herrington P., 1996 *Climate change and the demand for water*. HMSO, London

(2) Frederick K.D., Major D.C. and Stakhiv E.Z., 1977, *Water resources planning principles and evaluation criteria for climate change: summary and conclusions.* Climate change 37 (1), 7-23

higher precipitation levels may mean increased levels of leaching so that concentrations increase with flow.

The effect of drying out is considerable, especially on the production of nitrates - an increased release of the order of 200% has been noted.(1) Preliminary findings suggest that climate change will bring about significant changes in the amounts of potentially leachable organic matter. The occurrence of summer drought followed by increased autumn / winter rains will be increased under climate change.

Estuarine and Lake Water Quality

Lower flows, under climate change, will have implications for the whole estuarine environment. The flushing of tidal reaches between tides by fresh water is an essential component of estuarine dynamics. The influx of fresh water controls the salinity, amounts of sediment and other loadings including pathogens, and thus the greater part of water quality. Projected sea level rise under climate change would have less effect on salinity than predicted reductions in flows of fresh water.(2)

Concerns over the reduced flushing of salinity, sediments, pathogens and de-oxygenated 'slugs' with reduced river flows,(3) put extra emphasis on the need to conserve upstream flows, despite the dearth of knowledge concerning the processes and dynamics of estuarine systems.

Enhanced climate variability, or generally drier conditions, can affect lakes in very complex ways. Climate temperature variability contributing to in-lake water fluctuations will affect sediment oxidation levels. Concomitant changes in water oxygen concentrations, light and heat penetration in lake waters will impact aquatic organisms, notably reducing cold water farming species.(4)

In further studies several researchers have noted that as temperatures rise, in-lake water residence time of chemicals increases and chemical reaction response time is longer. A positive relationship between warming and alkalinity has been established.(5)

Land use changes may change the acid / alkaline condition of drainage waters.

(1) Freeman C., Lock M.A., Hughes S & Reynolds B., 1997 *Nitrous oxide emissions and the use of wetlands for water quality amelioration*. Environmental Science Technology 31, 2438-2440

(2) Dearney M.P & Waller M.N.H., 1993 *Impacts of climate change on estuarine water quality*. HR Wallingford Report to the Department of Environment.

(3) Arnell N.W., Jenkins A. & George D.G., 1994 *The implications of climate change for the National Rivers Authority*. HMSO, London

(4) Yan N.D., Keller W., Scully N.M., Lean D.R.S., Dillon P.J., 1996 *Increased UV-B penetration in a lake owing to drought-induced acidification*. Nature 381, 141-143

(5) Psenner R & Schmidt R., 1992 *Climate driven pH control of remote alpine lakes and effects of acid deposition*. Nature 356, 781-783

The impacts of higher mean annual temperatures on lakes in the UK may derive from worsening water quality and changes in species composition and structure.

Changes to Soil Matrix

Soils with high clay content are prone to shrinkage and cracking on drying out. On the return of wet conditions, the soil swells, but cracks and fissures can remain for some time after the onset of rains. Instead of a slow percolation process during which nutrients and other active agents could be taken up by plants or attached to clay particles, their entry to water courses is likely to be rapid.

The drier growing seasons and wetter winters under climate change will make this phenomenon more common.[(1)] Research projects funded by MAFF are currently under way with studies by the Agricultural Development and Advisory Service (ADAS) and the Soil Survey and Land Research Centre (SSLRC).

Urban Drainage and Sewage Networks

Precipitation of high intensity over urban or other relatively impervious landscapes rapidly produces storm flows in drainage networks. This includes sewers in many situations. Solids and other contaminants which have accumulated during preceding dry weather are flushed through the system. Sewage treatment works may flood, causing raw sewage to enter water courses. The potential for damage from chemical, biological, or particulate matter is high.

Modern storm runoff networks present less risk of raw sewage entering water courses. However, surface runoff can contain a vast array of chemical and physical agents such as hydrocarbons, herbicides and de-icing agents which come from roads and airport installations. Modern road schemes have measures built into their drainage systems which allow for a degree of storage / sedimentation to take place in storm conditions.

Erosion from Agricultural Land

Significant soil erosion events are normally produced because soils become detached and transported down-slope by large amount of intense running water. The physical and chemical effects can be notable if they enter water courses. Changed velocities of carrying waters with change of slope or increased friction to flow may cause soil particles to become deposited at lower elevations before reaching the watercourse. Arable land may be most at risk to soil erosion events, but upland grazing areas can also be affected.

(1) Armstrong A.C., Matthews A.M., Portwood A.M., Addiscott T.M. & Leeds-Harrison P.B., 1994 *Modelling the effects of climate change on the hydrology and water quality of structured soils.* In M.D.A. Rounsevell & P.J. Loveland (eds.), Soil Responses to Climate Change. NATO ASI Series 1, Global Environmental Change, 23, 113-136

Skinner *et al* [1] note that much of the phosphorous and pesticide losses from agricultural land is due to soil erosion. Favis-Mortlock and Boardman [2] conclude that erosion would be an increased problem in the wetter years of a changed climate.

The increased risk of eroded soils entering water courses under climate change can be mitigated, to a large extent, by the use of (flow modifying) buffer zones alongside water courses which drain land in landscapes at risk.

Agricultural Waste Products/Manures

The intensification of livestock production, notably poultry, pigs and cattle, in recent decades, produces vast quantities of manures and slurry which are spread on agricultural land. Modern cropping patterns use this means of disposal usually in the early autumn. Storage of these commodities therefore has become necessary. In addition, intensive outdoor pig production has recently gained popularity. Large quantities of organic waste can be spread on land. Other organic agricultural wastes which are disposed of on farmed land include silage effluent.

Direct entry of concentrated slurries or silage effluents to water courses is potentially catastrophic to the water environment. For example, silage effluent has a BOD 200 times greater than that of raw domestic sewage.[3] In addition to the risk of direct entry of these concentrated wastes, there is the question of their natural breakdown (after spreading on land) with subsequent mineralisation and the risk of nutrient leaching, into water bodies.

Skinner *et al* reported 2883 pollution incidents from farm wastes in the UK in 1993. Without changes in farming practice to reduce further the risks, increased autumn and winter precipitation under climate change would probably increase the frequency and magnitude of point-source agricultural pollution.

5.3.2 Increased Water Temperatures

Increased air temperatures with climate change will increase the temperature of surface waters. The high temperature sensitivity of many chemical and biological processes is arguably the fundamental reason for the importance of temperature to the aquatic environment.

(1) Skinner J.A., Lewis K.A., Bardon K.S., Tucker P., Catt J.A. & Chambers B.J., 1997 *An overview of the environmental impact of agriculture in the UK.* Journal of Environmental Management 50, 160-169

(2) Favis-Mortlock D. & Boardman., 1995 *Nonlinear responses of soil erosion to climate change: a modelling study of the UK South Downs.* Catena 25, 365-387

(3) Skinner J.A., Lewis K.A., Bardon K.S., Tucker P., Catt J.A. & Chambers B.J., 1997 *An overview of the environmental impact of agriculture in the UK.* Journal of Environmental Management 50, 160-169

Increases in water temperature would increase the rate of operation of biogeochemcal processes within rivers. Sensitivity to temperature varies between processes. Denitrification processes are more temperature sensitive than nitrification processes so that, in a situation of constant river flows, higher temperatures would result in the removal of nitrate. However, often temperature effects may be offset by flow discharge effects.

The solubility of gases

Gas solubility decreases with temperature. Higher water temperatures would generally reduce holding capacity of dissolved oxygen and other atmospheric gases. This would be compounded by lower volumes of water and /or higher concentrations of organic matter. Lack of oxygen in slow moving waters can produce spectacular kills of susceptible fauna including fish populations. Higher temperatures will also increase rates of breakdown of biological material and thus impact negatively on levels of dissolved oxygen.

Temperature related growth and recycling rates

In UK waters, expansion and growth of biological populations tend to be limited by low temperatures. As air temperatures and thus water temperatures increase, lower threshold limits are exceeded and growth accelerates markedly, with implications for nutrient rich waters. For example, phytoplankton growth rates increase rapidly between 10 and 20°C and only begin to decline at temperatures above about 25°C.[1]

Growth can be limited through the limiting nutrient phenomenon. It is likely that bacterial action would be enhanced with higher water temperatures thus the possibility of a more intense 'boom and bust' cycle.

Increased temperatures can affect ecosystems by exacerbating nitrogen saturation if higher temperatures lead to a release of nitrogen in excess of that taken up by plants or immobilised in the soil. The effects of drought and high temperatures on nitrate leaching can persist for several years, for example, at Plynlimon in Wales.[2]

Effects on Pathogenic Organisms

Higher temperatures along with raised nutrient levels are likely to provide favourable conditions for the multiplication of water borne bacteria, some of which are potentially harmful to human populations. This may be offset by increased populations of higher predator organisms. Higher water temperature is likely to reduce the survival time of virus populations and protozoal cysts due to an increase in predation.

(1)Arnell N.W., Jenkins A. & George D.G., 1994 *The implications of climate change for the National Rivers Authority*. HMSO, London

(2) Reynolds B., Emmet B.A., Woods C., 1992 Journal of Hydrology 136, 155-175

Even if potentially harmful organisms do not have enhanced survival prospects in warmer conditions, lower flows and more intensive water use will increase the dangers from pathogenic organisms.

Temperature and Limits to Habitat

Temperature is an important environmental variable in the survival of biological species. Arnell *et al.* found that there are implications of increased temperatures for some cold water species in the north of England and Scotland. Most fish species in the UK would not experience significant impacts however. For example, White and Knights[(1)] found relationships between temperature and the riverine migration of eels for the Rivers Severn and Avon in the west of England.

Direct action to prevent increased temperature seems to be unfeasible. Maintaining flow levels, by avoiding over abstraction, especially where groundwater is a major component of flow, offers possibilities of mitigation. There are other indirect mitigation measures. For example, in the case of low dissolved oxygen status, artificial aeration is a management option. The efficiency of sewage treatment works is likely to increase with higher temperatures.[(2)]

The Incidence of Algal Blooms

Temperature, light levels, eutrophic status and residence times of waters within water bodies, are among the controlling factors of algal blooms. Recent warmer and drier summers have been seen to be favouring the formation of algal blooms (which in turn reduces dissolved oxygen), hence the connection with summers under global warming. However, the lack of an increased occurrence of blue-green algae during the exceptionally warm summer of 1995 in the UK. Palutikof *et al*[(3)] has put into question the simple connection with warm summers.

Changes to Land Use

Given the predicted changes in seasonal precipitation, temperature and potential evapotranspiration, there will be changes in the geographic suitability for some aspects of current agricultural practice. This may affect land use change. In addition, the increased atmospheric CO_2 content will generally enhance crop growth.

Much research has gone into the application of climate change scenarios to agricultural systems and maps have been produced which indicate the future

(1) White E.M. & Knights B., 1997 *Environmental factors affecting migration of the European eel in the Rivers Severn and Avon, England.* Journal of Fish Biology, 1997, 1104-1116

(2) CCIRG (Climate Change Impacts Review Group), 1996: *Review of the potential effects of climate change in the United Kingdon.* Department of Enviornment, HMSO, London

(3) Palutikof J.P., Subak S., & Agnew.M. D. (eds), 1997b *Economic impacts of the hot summer and unusually warm year of 1995.* Report for the Department of Environment, University of East Anglia, Norwich

geographical location of the most suitable growing areas. However, much still needs to be known regarding the impacts of present day agricultural practice on water quality and the prediction of geographical changes to cropping patterns under climate change. A study on the interactions between climate change, agriculture and water is being undertaken in association with UKCIP.

5.4 ATMOSPHERIC QUALITY

5.4.1 Air Pollution Dispersion and Transport

Meteorological conditions control the dispersion of pollution once it is released into the atmosphere.

Long-term changes in wind speed and direction are known to have affected the concentration of aerosol sulphate over Central England.(1)

Summer surface ozone "episodes" are strongly associated with particular circulation patterns,(2) although wind speed is also.(3) Winter surface ozone episodes are similarly dependent on (different) circulation patterns, and on an opposite relationship with wind speed.(4)

Circulation patterns have also been shown to have a strong control on sulphur and nitrogen species including transport of emissions from elsewhere in Europe.(5)

Emission rates will represent the primary control on ambient concentrations if they change significantly over decades. Nevertheless, past observed behaviour indicates that, even when pollutant and precursor emissions were changing markedly, trends in pollutant concentrations on the yearly to decadal timescale were strongly influenced by changes in atmospheric circulation patterns (e.g. Davies *et al.*, 1992a in the case of sulphate; Davies *et al.*, 1992b in the case of surface ozone).

(1) Davies T. D., Pierce C.E., Robinsons H.J. & Dorling S.R. 1992a *Towards an assessment of the influence of climate on wet acidic depostition in Europe*. Environmental Pollution 75, 111-119

(2) Guicherat R. & H. van Dop, 1997 *Photochemcial production of ozone in Western Europe (1971- 1975) and its relation to metereology*. Atmos. Environ. 11, 145-155

(3) Davies T.D., Kelly P.M., Low P.S.., Pierce C.E, 1992b *Surface ozone concentrations in Europe: links with the regional scale atmospheric circulation*. Journal of Geophysical Resources 97 (D9), 9819-9832

(4) Davies T. D. and Schuepbach E., 1994 *Episodes of high ozone concentrations at the Earth's surface resulting from transport down from the upper troposphere/lower stratosphere*. Atmos. Environ. 28 (1), 53-68

(5)Dorling S. R. and Davies T. D.,1992 *Cluster analysis: A technique for estimating the synoptic meteorological controls on air and precipitation chemistry - results from Eskdalemuir, South Scotland*. Atmos. Environment 26A, 2583-2602.
Dorling S. R. and Davies T. D., 1995 *Extending cluster analysis - synoptic meteorology links to characterise chemical climates at six north-west European monitoring stations*. Atmos. Environment 29(2), 145-167.

5.4.2 *Pollutant Deposition*

Many studies have demonstrated the dependence of wet deposition on meteorology[1] and in particular on the incidence and distribution of precipitation.[2] The type of precipitation is also important. Snow, for example, is a particularly efficient scavenger of particulate material[3] and removes relatively more nitrate than does rainfall.

Of particular note is the fact that wet deposition of pollutants is frequently highly 'episodic', especially in regions more remote from sources.[4] Davies *et al.* 1992c showed that up to 40% of wintertime total wet deposition of some soluble ions in the Scottish Highlands can occur during one event. A small change in the frequency of the atmospheric circulation pattern associated with such episodes could have a very strong effect on annual deposition patterns.

Total pollutant deposition is the sum of wet deposition, dry deposition, and what has sometimes been called 'occult' deposition, or interception by cloud droplets. Over the UK as a whole, only ~5-7% of total sulphur and nitrogen deposition is effected by cloud droplets, but it is concentrated in mountain areas where many sensitive ecosystems are located.[5] One of the possible consequences of global warming is an increase in cloud,[6] and a strengthening of the mountain-related precipitation mechanism.

5.4.3 *Implications of Climate Change For Pollutant Deposition*

Pollutant Critical Loads

Critical load assessments form the backbone of international efforts to reverse the environmental effects of acidic deposition. If critical load assessments fail to recognise the importance of climate variability or climate change, then there could be damaging consequences for the recovery of impacted ecosystems.[7]

[1] Moody J. L. and Sampson P. J., 1989 *The influence of atmospheric transport on precipitation chemistry at two sites in the Midwestern United States.* Atmos. Environment 23, 2117-2131.
Davies T. D., Tranter M., Jickells T. D., Abrahams P. W., Landsberger S., Jarvis K., Pierce C. E., 1992c *Heavily-contaminated snowfalls in the remote Scottish Highlands: a consequence of regional-scale mixing and transport.* Atmos. Environment 26A, 95-112.
Dorling S. R. and Davies T. D.,1992, *Cluster analysis: A technique for estimating the synoptic meteorological controls on air and precipitation chemistry - results from Eskdalemuir, South Scotland.* Atmos. Environment 26A, 2583-2602.
Dorling S. R. and Davies T. D., 1995, *Extending cluster analysis - synoptic meteorology links to characterise chemical climates at six north-west European monitoring stations.* Atmos. Environment 29(2), 145-167.

[2] UKRGAR (United Kingdom Review Group on Acid Rain) 1997 *Acid deposition in the United Kingdom 1992-1994.* AEA Technology plc. 175pp.

[3] Davies T. D., Tranter M., Jickells T. D., Abrahams P. W., Landsberger S., Jarvis K., Pierce C. E., 1992c *Heavily-contaminated snowfalls in the remote Scottish Highlands: a consequence of regional-scale mixing and transport.* Atmos. Environment 26A, 95-112.

[4] Smith F. B. and Hunt R. D., 1978. *Meteorological aspects of the transport of pollution over long distances.* Atmos. Environment 12, 461-477.

[5] UKRGAR (United Kingdom Review Group on Acid Rain) 1997 *Acid deposition in the United Kingdom 1992-1994.* AEA Technology plc. 175pp.

[6] Houghton, J.R., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. and Maskell, K., (eds.), 1996 *Climate Change 1996: The Science of Climate Change.* Cambridge University Press, Cambridge 572pp.

[7] Wilby R. L., 1995a *Critical loads' sensitivity to climate change.* Environmental Conservation 22, 363-365.

Hydrochemical Response

Relatively few hydrochemical responses occur to a specific pollutant deposition event. An exception is when large inputs of salt can lead to acidic episodes. Such episodes have been observed tens of kilometres inland in Scotland and Wales,[(1)] especially during vigorous autumn storms. Forested catchments may be particularly susceptible. A change in storm behaviour would have some implications for such episodes. A long-term change in pollutant deposition will lead to possible changes in the chemical status of catchments.

5.5 COASTAL MANAGEMENT

5.5.1 Sea Level Rise

The fluctuation of sea level on a global scale is a natural and well documented phenomenon. The potential hazards of erosion and flooding depend on relative sea level rise. Natural adjustments in the elevation of land (relative to global reference frame) are continually taking place through mechanisms which include tectonic and post-glacial adjustment processes. It is probable that these natural processes will modify the potential effects of global sea level rise. In the UK the basic trends in movements are for the north west to rise and the south east to sink relative to present sea level, thus dampening or exacerbating the effects of sea level rise depending on the geographical location.

Climate change will impact sea levels through higher temperatures. This causes a melting of terrestrial ice, and the thermal expansion of the oceans. Estimates of the degree of sea level rise have a high level of uncertainty attached to them. *Annex A* shows the range of sea level rise responses under the IPCC IS92a emissions scenario for the period 1990-2100. Titus *et al*[(2)] used 'subjective probability distributions based on expert opinion on twenty researchers and included IPCC emission scenarios to conclude that there is a 50% chance that greenhouse warming will add 34cm to sea levels by the year 2100, and a 5% chance that the figure could be 77cm or more.

Table 5.2 shows UKCIP estimates of increases in sea level taking account of natural land movements.

[(1)] *Langan S. J.*, 1987 *Episodic acidification of streams at Loch Dee, SW Scotland*. Trans. Royal. Soc. Edinburgh 78, 393-397.
Neal C., Christophersen N., Neal R., Smith C. J., Whitehead P. G., Reynolds B., 1988 *Chloride in precipitation and streamwater for the upland catchment of River Severn, mid-Wales; some consequences for hydrochemical models*. Hydrol. Processes 2, 155-165.

[(2)] Titus, J.G. & Narayanan, V., 1996 *The risk of sea level rise*. Climatic Change 33 (2), 151-212.

Table 5.2 ***Increases in sea level (cm) around the UK coast by the 2050s due to (i) global climate change only ("Climate") and (ii) to the combined effect of climate and natural land movements ("Net") under the UKCIP98 scenarios***

	Low		**Medium-Low**		**Medium-High**		**High**	
	Climate	Net	Climate	Net	Climate	Net	Climate	Net
West Scotland	13	2	20	9	28	17	74	63
East Scotland	13	8	20	15	28	23	74	69
Wales	13	18	20	25	28	33	74	79
English Channel	13	19	20	26	28	34	74	80
East Anglia	13	22	20	29	28	37	74	83

The increases are for 30 year means.

The change in mean sea level around the UK coast leads to large reductions in return periods for certain high tide levels around part of the UK coast. The UKCIP report shows that for Harwich, the return period for a tide level of 5.6 metres above datum falls from 100 years to ten by the 2050s. This is using a scenario based on atmospheric concentrations of greenhouse gases used in the IPCC IS92a emissions scenario, which has been widely used as a standard emissions profile.

The CCIRG report demonstrates how a 0.2 m rise in sea level could result in a 100 year event, (for example, breaching a sea defence wall), changing to a return period varying from 25 years to 5 years, depending on the location.

The change in extreme water levels is not necessarily the same as changes in the mean and is more difficult to assess due to uncertainty.

5.5.2 Changes in the incidence of storm conditions

The majority of impacts of sea level rise are likely to be experienced in the coastal zone and in estuaries through changes in the frequency or severity of storm events.(1) The two main processes affected by climate change are storm surges and wave action. Storm surges associated with changes in atmospheric pressure and wind fields cause changes in tide levels. Wave action is generated by wind fields, and wave conditions at the coast can be affected by water depths. Increased storm damage will affect erosion and flooding rates.

In the UK the most dramatic coastal flooding events are produced by storm surges. A combination of specific meteorological conditions involving low pressure systems, in conjunction with high tides and shallow coastal waters, provide the necessary ingredients. Particularly dangerous situations occasionally occur in the southern North Sea as illustrated by the dramatic events of 1953.(2) The land surrounding the southern North Sea is particularly

(1) CCIRG 1996 *Review of the potential effects of climate change in the United Kingdom*. Second report. HMSO, Department of Environment

(2)Pollard, M., 1978: *North Sea Surge: The story of the east coast Floods of 1953*. Terence Dalton, Lavenham, 136 pp.

prone to the effects of storms, when southward moving surges are funnelled and thus amplified by the Dutch and English coastlines.

The likelihood of increased storminess is less certain than the degree of sea level rise. Global climate models are not capable of simulating such local storm surge events. Nevertheless, there is still a significant chance that the effects of sea level rise will be exacerbated by an increase in storminess.

Sea level rise, with or without increased storminess, will add to existing problems of erosion and flooding experienced in coastal and associated low lying areas. Similarly, any increase in the frequency and/or magnitude of storm surge conditions would be cause for great concern with respect to flooding in the UK, with particular emphasis on low-lying coastal and estuary areas.

5.5.3 *The primary physical effects of sea level rise*

The increased threat from flooding

A direct effect of sea level rise is the increased risk of flooding in land areas such as coastal lowlands, natural and unprotected areas (for example, salt marshes), agricultural and urban areas which are at, or close to, existing sea levels. These areas are currently at risk of flooding but will come under an increased threat of periodic or permanent inundation, higher rates of deterioration to defences and increased likelihood of structural failure and breaching of defences. These impacts could be exacerbated by accelerated erosion of beaches and foreshores.

Changes in the frequency of river floods may exacerbate coastal flooding problems, *see Section 5.2.2.* However, there is a high level of uncertainty in predicting future change in river flood frequencies.

It is likely that engineering solutions will be found to prevent the flooding of strategic areas under threat, and natural (coastal) adjustment mechanisms will operate. About one third of the approximately 4500 km of the coastline of England and Wales is protected by artificial and/or semi-natural defences. The majority of these sea defences are to be found in the East Anglian region.[1]

The potential effects of sea level rise vary according to the response of the coast, including natural and engineered systems. The effects on wetland may well display a dynamic and non-linear response. In locations where there are no elevated-lowland areas further inland or where artificial protection is in place, inland migration will be prevented.[2]

[1] Turner, R.K., Adger, N. & Doctor, P.,1995: *Assessing the economic costs of sea level rise.* Environment and Planning A 27, 1777-1796.

[2] Nicholls, R.J., Hoozemans, F. M.J. & Marchand, M., 1997: *The impacts of sea-level rise on coastal areas.* Climate change and its impacts: a global perspective. UK Met. Office for DETR, 16 pp.

Increased coastal erosion

The geomorphic power of the sea, with respect to coastal processes is likely to be enhanced by virtue of any rise in relative sea levels. Gradual deepening of immediate offshore waters allows for an increase in wave energy which increases the ability of waves to dislodge cliff or other deposits and, at the same time, provides more energy for the lateral removal of dislodged material. (1) However, increased erosion may lead to increased deposition in areas where accretion can occur. The increase in erosion may be self limiting if accretion strengthens natural coastal protection and leads to a return of shallower margins.

It is probable that coastal defences may be realigned sacrificing small areas of the coastal margin to concentrate engineered efforts on more developed areas. This will produce hot bed areas of erosion and thus greater loss to the sea. Estimates of erosion rates, under climate change, due to increases in relative sea level and through the selective abandonment of existing protection regimes are large for the East of England. Values ranging between 6 and 18 metres per year are quoted by the Countryside Commission(2) assuming that retreat rates are proportional to rates of sea level rise. Coastal sediments so produced will not all be lost and accretion may be enhanced locally. Erosion rates are likely to be more conservative. Bray and Hooke(3) have predicted the response of eroding cliffs to sea level rise. They found that recession could increase by between 22% and 133% by 2050 due to sea level rise for cliffs on the South coast. The largest difference in rate was about 1 metre per year.

Table 5.3 Summary of coastal response to sea level rise, assuming no further protective measures

Type of zone	Likely response
Sandy beaches	Landward migration and profile adjustment if sufficient sediment store
Gravel beaches	Landward migration by 'rollover' mechanism if no constraining structure
Protected coasts	Inflexible; beach loss and scour, sea wall overtopping and structural damage
Eroding cliffs	Increased instability and recession resulting in greater sediment yields
Hard rock cliffs	Relatively unaffected
Wetlands and saltmarshes	Highly vulnerable. Can survive by inland migration if unconfined and adequate sediment supply

(1)Countryside Commission, 1996 *Climate change, acidification and ozone - Potential impacts on the English countryside.* Countryside Commission, CCP 458.

(2)Countryside Commission, 1996 *Climate change, acidification and ozone - Potential impacts on the English countryside.* Countryside Commission, CCP 458.

(3) Bray, M J and Hooke, J M, 1997, *Prediction of soft cliff rock with accelerating sea level rise,* Journal of Coastal Research, 13,2.

Beaches: amenities and coastal protection

Finer beach materials are deposited in quiet periods (given the supply of sediment). Beach material is redistributed with stormy seas, thus reducing water depth in the near shore and causing waves to break further out with the dissipation of much of their energy. This natural process reduces the attack from further erosion with a controlled inland migration of the coast line.

Coarser beach materials behave in different ways and, in most respects, are more resilient to change by natural processes. Whilst there are differences between the actual dynamics of the protective mechanisms of sand and gravel beaches, the overall protective effects are similar. Any obstruction, artificial or otherwise, which prevents migration of the beach inland and/or the supply of new sediment is likely to prevent future natural equilibrium (stabilisation) states. Subsequent beach instability threatens serious consequences for land which comes under its protection.

Engineering structures may well reduce the chances of accretion and thus natural protection on a localised scale. If, in this situation, natural beaches and other forms of 'soft' protection on the seaward side of, for example, sea walls are not maintained by accretion, the structure becomes very vulnerable to attack by the sea. This includes the risk of collapse and/or overtopping of sea defences through increased wave energy.

5.5.4 Other coastal features

Saltmarsh and Mudflats

These coastal habitats are vital to the maintenance of a significant part of the natural environment. Their function includes those of feeding/roosting ground for large bird populations, nursery area for fish populations, waste treatment of natural and unnatural compounds and nutrient recycling. Mudflats are particularly important for their role in the provision of invertebrate food sources for birds. Changes in submersion and erosion/sedimentation patterns would affect the distribution of mudflat invertebrates and thus their habitat potential.

In addition, saltmarshes offer coastal protection by their ability to dissipate wave energy in high seas. Salt marsh habitats are potentially highly vulnerable to inundation and erosion.[1] As with beaches, they adjust to rising sea levels given gradual change, an adequate supply of sediment and the freedom to migrate inland. Estimates of the past rates of accretion in salt marsh suggest maximum sustainable rates of 5-6 millimetres per year. This is about the same as projected rates of sea level rise under global warming. However, sediment supply is likely to be limited due to river regulation and coastal protection so that accretion rates cannot be maintained. This may lead to salt

[1] Goudie, A.S., 1996: *Geomorphological 'hotspots' and global warming.* Interdisciplinary Science Reviews 21 (3), 253-259.

marsh converting to mud flat.[1] The lack of freedom for salt marsh to migrate inland, with constraint by sea walls and embankments, has been highlighted by English Nature.[2]

Salt marsh habitats are vital to the maintenance of a significant part of the natural environment. Their function includes those of feeding grounds for large bird populations, nursery area for fish populations, waste treatment of natural and unnatural compounds, and nutrient recycling. In addition, they offer coastal protection by their ability to dissipate wave energy in high seas.

Estuaries

Estuary saltmarsh and mudbank areas provide an essential component of the habitat of many forms of life including large populations of sea birds.

Rising sea levels will deepen and widen estuaries (where lack of containment permits) with an increased salt water penetration inland at high tides. There may be a reduction in the amounts of riverine sediment discharged to saltmarsh areas and adjacent coastal zones. This will reduce further the amount of material for beach building and other accretion processes. Fresh water drainage and its load of discharged pollutants may not flush out to sea with implications for water quality. In addition, there may be problems for land based sewage and other effluent disposal in that changed hydraulic gradients could inhibit efficient operation of drainage systems. Shaladan *et al.*[3] predicted costly engineering solutions to predicted problems, under different sea level rise and storm scenarios, in a case study which focused on Gosport, southern England.

As with coastal features, landward migration of saltmarsh, mudbank and other wetland features would occur naturally but the presence of engineered flood protection and other such works would provide impenetrable barriers. In addition, there are maximum sustainable rates for migration (if space permits) and rates of sea level rise under global warming may well be overwhelming.

5.5.5 *Secondary implications of sea level rise: economic and other considerations*

Large areas of lowland, in some cases penetrating many miles inland from the coast, are at threat from sea level rise. *Figure 5.1* shows the land at or below sea level in the UK. The value of low-lying coastal areas is incalculable. Land use includes:

(1)Bray, M.J.,Hooke, J.M, & Carter, D., 1997 *Planning for sea-level rise on the south coast of England: advising the decision makers*. Transactions of the Institution of British Geographers 22, 13-30.

(2)English Nature, 1992: *Coastal zone conservation: English Nature's rationale, objectives and practical recommendations*. English Nature, Peterborough.

(3)Shaladan, M.J., Riley, M.J. & Tosswell, P., 1995 *The impact of climate change on maritime local authorities drainage aspects*. Proceedings of the Institution of Civil Engineers - Municipal Engineer 109 (2), 120-127.

- industrial and urban developments, for example, low lying parts of the Thames estuary - much of this now protected by the Thames Barrier and other flood defences;

- recreational / other amenities;

- national conservation environments, for example, the Norfolk Broads;

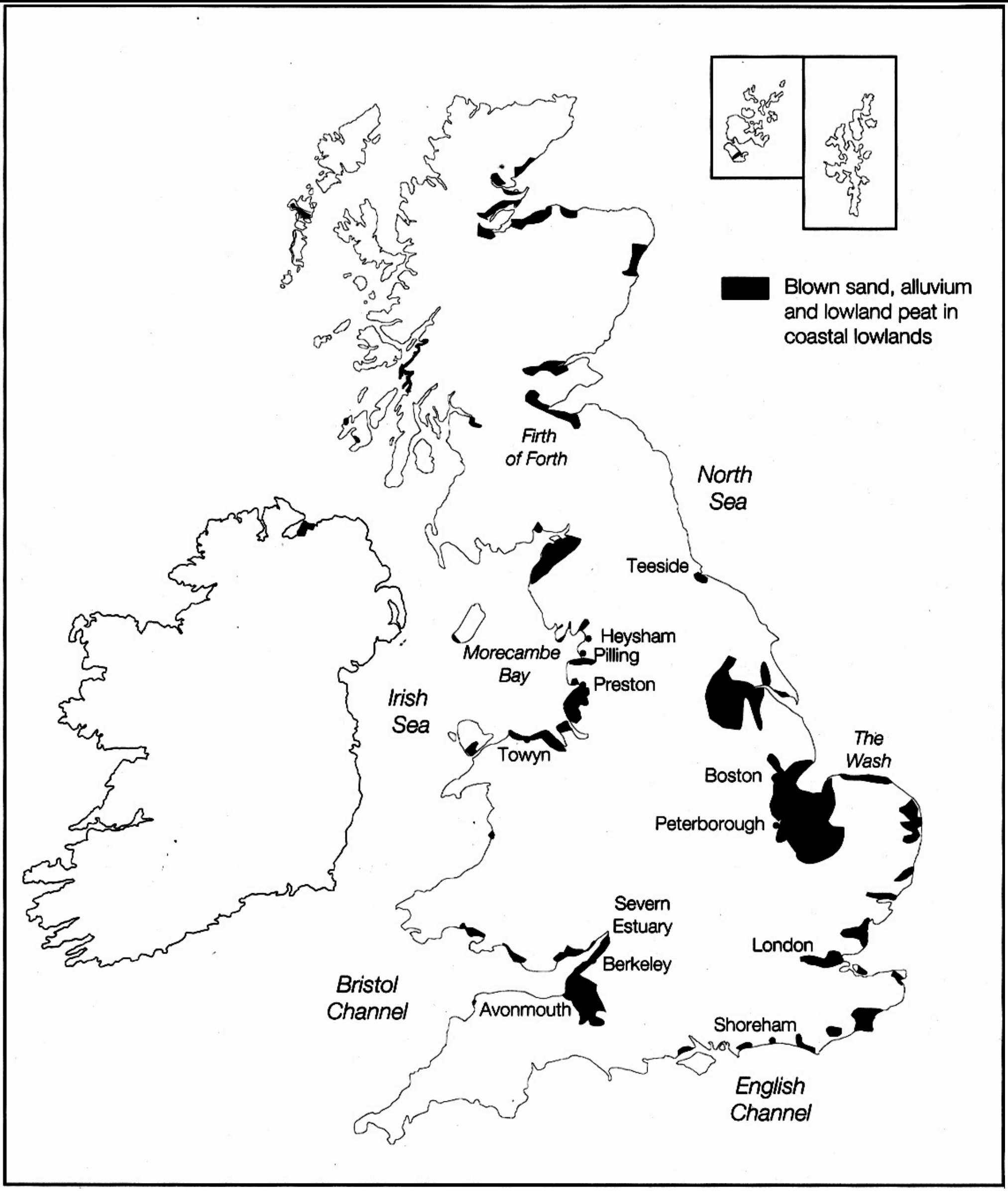
- prime agricultural land, for example, the Cambridgeshire fens with over 40,000 ha.

About 10% of conservation sites are at or near to sea level. Similarly, around 40% of all UK manufacturing industry is to be found along coastlines and estuaries. Around 57% of UK agricultural Grade 1 land is found at elevations below 5 m.[(1)] Periodic or permanent inundation by the sea would be catastrophic.

Many of these areas already have a complex infrastructure of flood protection against known extremes. Due to their low elevation, they often have sophisticated and vulnerable drainage networks to facilitate particular land use practices.

[(1)]CCIRG (Climate Change Impacts Review Group), 1996 *Review of the potential effects of climate change in the United Kingdom*. Department of the Environment, HMSO, London, 247pp.

Figure 5.1 *Map of the UK Indicating the Land at or Below Ordinance Datum (from CCIRG, 1996)*



5.6 *CLIMATE CHANGE IMPACTS AND AGENCY FUNCTIONS*

5.6.1 *Water Resources*

Climate change will add to the complexities of the water abstraction process in the sense that reviews of the supply / demand balance will need to take account of changes in supply in addition to demand shifts. Supply will be affected by changes in rainfall and changes in temperature patterns which affect evapotranspiration rates. Demand will be affected by increased demand for irrigation water in the agricultural sector in areas where it is least available and increased demand from a growing domestic sector in periods of high temperature. The major tool for incorporating climate change into long-term water resources management is through the Water Resources Plans by each of the water companies which will form the basis of a 'Water Resource Strategy' produced by the Agency. The individual plans are based on 20-25 year planning horizon and revised on an annual basis. They will include some indication of the expected impacts of climate change, the options for responding to these impacts and the financial implications of doing so.

Links with other Agency Functions

The role of the Agency's Water Resource function is to balance the different users of water resources thereby ensuring that existing management and future development is carried out in a sustainable manner. Implicit in this role is the interaction of the Water Resources function with other functions of the Agency. Those which will be particularly affected by climate change impacts on water resources are:

- biodiversity and navigation which will be impacted by changes in water quantity directly as a result of changes in precipitation levels and evapotranspiration rates and indirectly through demand for increased abstraction with its associated impacts on water quality;

- agriculture and rural land use will be affected through changing patterns of land use as a result of climate change. This will occur through differences in the intensity, spatial and seasonal demand for water and through increased erosion and leaching on water quality;

- industrial waste water discharges may impact on water resources and their quality.

5.6.2 Water Quality

The water quality function has the power to control water quality in rivers mainly through effluent discharges from industry. However, as noted above, climate change will have direct and indirect impacts on water quality in a number of ways which are less easily controlled by the Agency such as:

- changing river flows (as a result of precipitation changes, increased rates of evapotranspiration in the summer);

- increased surface run-off and incidences of leaching (as a result of extreme events and precipitation variability exacerbated by changes in the soil matrix);

- changes in bacterial activity and algal blooms (as a results of temperature increases);

- increasing alkalinity of lakes (temperature changes);

- impacts of rising sea levels on fresh water drainage of discharged pollutants from estuaries.

There may be a direct link between river quality and flow (or in extreme cases even the existence of smaller rivers). While the effluent from sewage treatment works could improve in quality due to increased effectiveness of the self-purification process at higher temperatures, other non-climate related factors, such as increasing water quality standards, may lead to increased costs of water pollution control for waste water treatment plants. This could lead to a consolidation of waste water treatment with closure of smaller plants. Waste water would be transferred to a smaller number of larger plants. Some of these small plants can be very significant sources of flow for rivers. Removing the waste water treatment plant may effectively remove the river. There may be trade-off between clean rivers and maintaining a larger number of dirtier rivers.

Links with other Agency Functions

Maintaining water quality is clearly of key importance to achieving other Agency functions such as water resources management, fisheries and conservation. Water quality can also be impacted by other Agency functions such as:

- waste management through leaching associated with practices such as sewage sludge application to farmland and risks of storm water fouling with sewage;

- water resources and its responsibilities over maintaining the balance between supply and demand of water;

- flood control and its responsibilities over consents that might affect watercourses as well as fluvial, tidal and sea defences;

- responsibilities for the technologies used by industry and the resultant discharges to soil and water under IPC;

- land use practices and associated problems such as soil erosion.

5.6.3 Flood Defence

Flooding can result from two significant potential impacts of climate change:

- a rise in mean sea level;

- an increased frequency and intensity of extreme storm events.

Estimations of the likely frequency of inundation and the need for coastal protection can be based on projections of sea levels rise. The IPCC ‘best estimate trend' is accepted as the most appropriate and as such has been adopted by MAFF in guidelines for coastal defences and are confirmed in the PAGN notes:

- Anglian, Thames and Southern Regions: 6mm / year;
- North West and Northumbria: 4mm / year;
- Remainder: 5mm / year.

These allowances were intended to be applied to the period 1990-2020 and take into account global sea level rise and long-term vertical geological movements. They are based on a global sea level rise of 4.5 mm / year, adjusted to Environment Agency Regions. Other scenarios have been used for specific defences, eg the Thames barrier, was based on a projected 8mm / year rise in sea level. The UKCIP98 projection for global mean sea level range from 2 to 9 mm / year, based on the UKCIP global warming scenarios.

The other complicating factor is the increase in the frequency of storms under climate change. Storms will lead to greater frequency of flooding.

The impacts of climate change on flooding of river basins occur on a localised scale and are therefore more difficult to predict. Regional climate projections at fine resolutions carry much uncertainty, *see Section 4.2*, although the Hadley Centre are in the process of developing finer resolution models.

Links with other Agency Functions

Flood control activities will protect some areas of developed and rural land (with associated biodiversity and recreational value) and consequently determine erosion rates for unprotected land. Flood protection works may, in some cases, impede the movement of saltmarsh, mudflats and other wetland features in response to increased coastal erosion.

5.6.4 Conservation

The Agency's ability to discharge its conservation functions may be affected by climate change. While the greatest threats to conservation and recreation are from the direct effects of human activities such as agricultural practices, building developments, water and soil contamination and visitor over-use, future climate change represents one additional stress upon the natural environment that needs to be accounted for in the future planning and management policy at the Agency.

The potential impacts of climate change on the terrestrial environment have been reviewed by Cannell in both the CCIRG reports (1991 and 1996). These reports stress the sensitivity of natural biota to climate variability, in particular changes in extreme events (droughts, unseasonal frosts and higher wind speeds), an increase in the magnitude and frequency of soil moisture deficits, temperature dependent threshold changes such as elimination of critical periods of freezing, changes in growing season, and sea level rise. Changes in these characteristics of climate may lead to the following (CCIRG, 1996):

- changes in the composition of existing communities;
- migration and invasion of species;
- losses and extinctions;
- outbreaks of pests and diseases;
- landscape and habitat changes.

Specifically the following habitats are expected to be impacted:

- the loss of montane plant communities;
- more frequent drying out of wetlands;
- invasion of coastal dunes by alien species;
- decline of broad-leaved woodland due to increased frequency of summer moisture deficits.

The impacts on flora and fauna from climate change will depend on the definitions of conservation status over time. Conservation objectives will need to reflect the feasibility and appraisal of adaptation options available, *See Section 7.5*.

Impacts and links with other Agency Functions

The conservation function will also be affected by how other Agency functions are managed in response to climate change, specifically:

- water resources which could result in increased water abstraction rates with associated impacts on flows and water quality;
- flood control works to protect land and buildings from sea level rises and could impede backward migration of some habitats and lead to increased coastal erosion rates of others (such a sand dunes);
- IPC regulatory controls which could be tightened to reduce air borne pollutant deposition rates on plants, animals, water courses and buildings;
- fisheries and stocking policy and the introduction of exotics;

- increased demand for water based and rural recreation could affect conservation negatively through increased noise, transport and litter disturbance and positively by providing additional revenues for conservation management.

5.6.5 Fisheries

The aquatic habitats of England and Wales support forty two native fish species that rely on freshwater for all or part of their life cycle, as well as ten or more introduced species.(1) Climate change may affect fish populations through the interaction of four factors:(2)

- direct effects of increased water temperatures on physiological factors such as growth, reproduction or survival;

- indirect effects on fish habitat through changes in river flows, lake levels and water quality;

- changes in habitat may cause changes in fish food availability;

- changes in flow regimes and ocean circulation may affect migration patterns.

Genetic diversity is a key factor in enabling any population to survive and adapt to change. Protecting genetic diversity of fish stocks and reducing the negative impacts of the many other factors that affect fish populations will maximise opportunities for fish populations to adapt (Environment Agency, 1999).

The magnitude of change under predictions of climate change current in 1999 will provide both opportunities and threats to fish populations. Coarse fish, at their northern limit in Britain, would extend their range north, but inhabitants of cooler waters, particularly Atlantic salmon, would gradually be displaced from southern rivers. Alien (non-native) fish species may become established.

The impacts of changes in freshwater fisheries are difficult to quantify but may include:

- increased opportunities and diversity in recreational coarse angling;

- reduced opportunities in recreational and commercial migratory salmonid fisheries;

(1)Winfield, I.J., Fletcher, J.M. & Cragg-Hine, D. (1994) *Status of rare fish.* NRA R&D Project Record 249, Volume 2, 108pp.

(2)Arnell, N.W., Jenkins, A. & George, D.G., 1994 *The implications of climate change for the National Rivers Authority.* Final Report (R&D Report 12) to the National Rivers Authority. HMSO, London, 94pp

- changes in the contribution of freshwater fish species to biodiversity and conservation capital;

- changes in the overall freshwater fish species composition in England and Wales as alien species establish breeding populations.

Links with other Agency Functions

Activities regulated by other Agency Functions which may further impact on fisheries through their responses to climate change will include:

- increased abstraction of water resources;

- water quality and land use through changes in the nutrient status of surface waters and through sub-lethal changes in water quality (such as endocrine disruptors) and changes related to modified dilution of discharges;

- flood defence and navigation works resulting in habitat modification;

- impacts of changes in land use such as soil erosion and river response to rainfall;

- IPC will determine the extent of acidification on juvenile salmon and trout in upland areas.

5.6.6 Navigation

The Agency's ability to maintain and expand waterways will be affected by climate change through a number of ways:

- low flows affecting the maintenance of waterways;

- a greater number of storm events which increases the possibilities of obstruction to navigation;

- greater or faster vegetation growth in navigation;

- changes to soil matrix may endanger the integrity of waterways and hence the security of the navigation channels;

- increased incidence of flood from more extreme wet days.

During summer months in the south of England river flows are expected to be lower. There are a number of possible consequences:

- longer waiting periods at locks;

- conflicts between water users including conservation, abstraction and navigation;

- requirements for costly capital works such as back-pumping.

In addition to these impacts on the navigation resource and thus the "supply" of navigations, climate change will also have an effect on the demand for water-based recreation. Temperature increases will make all kinds of water recreation, including inland boating, more attractive. There is also likely to be increased conflict between larger numbers of boaters and other recreational users of the waterways.

Links with other Agency Functions

Activities regulated by other Agency Functions which may further impact on fisheries through their responses to climate change will include:

- water resources through increased abstraction of water resources,

- conservation through its impacts on restrictions to navigational activity;

- changes in land use through changes in soil erosion (compounded with increased rates of rainfall and storm events) on the navigability of waterways;

- flood control activities and their impacts on the water levels of rivers.

5.6.7 Recreation

Perry and Smith in CCIRG (1996) present an assessment of climate change impacts on recreation in England and Wales as does Arnell *et al.* [(1)] but with the focus on water-based recreation. As is the case for other functions of the Agency, climate change will not be the only pressure changing in the future. Future trends in recreation and tourism due to warmer temperatures and possibly drier summers will also result in different demands on resources. The impacts on coastal resources may be significant. Many coastal resorts have beaches which are constrained from inland migration which will affect the geographical distribution of coastal recreation activity. Pressure could be put on locations where beaches are still able to move inland. These may be locations where there is high conservation value, for example, beaches backed by dune systems.

There are a number of factors that contribute towards a likely increase in the level of demand for recreation associated with climate change.

[(1)] Arnell, N.W., Jenkins, A. & George, D.G., 1994, *The implications of climate change for the National Rivers Authority*. Final Report (R&D Report 12) to the National Rivers Authority. HMSO, London, 94pp.

- increased temperatures increasing domestic demand;

- increased temperatures in southern Europe tending towards a change in the pattern of international and domestic demand functions for recreation.

As there is an ongoing move to improve the quality of water in rivers and lakes in the UK, eg through the requirements for good status under the Water Resources Framework Directive, demand for water recreation will increase alongside some reduction in resource availability, especially during summer months in southern England.

Increases in recreation and associated car use will lead to increased emissions of greenhouse gases - the very gases that generate temperature changes.

Links with other Agency Functions

Given that the Agency delivers its greatest contribution to its recreational duties through the work of its other functions, it is also likely to be greatly impacted by the work of other functions. These impacts include:

- water quality determines the extent of bathing and other recreational uses;

- process industries regulation activities will impact on the levels of land pollution and associated water pollution through leaching action (compounded through increases in extreme events and increasing polarisation of rainfall patterns in winter and summer);

- flood alleviation schemes may make improvements to landscaping, and availability of footpaths, seating and interpretation thus increasing local amenity. Structures such as weirs and sluices can be modified to improve conditions for white water canoeing;

- flood control activities and their impact on coastal resources such as beaches;

- maintenance of inland waterways for boating activities.

5.6.8 Process Industries Regulation

Climate change affects the Function through changes in the impacts of air pollution. This is due to:

- changes in wind speed and direction and their effects on the dispersion of pollutants;

- changes in precipitation frequencies and intensities on pollution deposition;

- interaction of sunlight on ozone formation.

Links with other Agency Functions

The Agency's requirements under IPC will be affected by other Agency Functions through the following ways:

- water quality requirements which will impact on the content and quantity of effluent discharge thus affecting the requirements of IPC;

- Agency Functions and activities that influence Agency objectives for the management of water resources (such as water abstractions, Navigations, Fisheries, Conservation and Recreation) will affect water effluent limitation levels required under IPC;

- Agency Functions (such as Conservation, and Recreation) that influence Agency objectives for land pollution limitation levels will affect the IPC requirements for air emissions.

5.6.9 Waste Management

The Agency's ability to discharge its waste management functions may be affected be climate change through:

- *Changes in temperature.* In general, modern, relatively deep landfills are well insulated. Internal temperatures may be high (in excess of 40ºC) and are affected more by decomposition activity than ambient conditions. If emission rates were to be affected by ambient temperatures, the effect would be on the distribution of emissions over time rather than total emissions. Temperature may affect odour effects from landfill sites and the activity of pests, ie, higher temperatures resulting in marginally higher releases of odorous volatile compounds and the potential for increased fly infestation.

- *Changes in precipitation.* Higher rainfall may result in increased waste moisture content and a slight increase in the rate of degradation and hence landfill gas evolution. More intense rainfall will impact on landfill management, especially in the management of leachate.

- *Changes in the levels of water tables.* Landfills that are lined will not be affected by groundwater levels unless water levels rise sufficiently to cause the liner to be 'lifted' prior to waste emplacement. Rising groundwater levels at older, unlined landfills sites would cause saturation of the lower levels of waste in the site. The main effect is likely to be on leachate generation and the attenuation of leachate once in the soil. Impacts on groundwater and local water balances are highly uncertain which, likewise, makes landfill gas emission rates uncertain.

- *Increased risk of flooding.* Inundation could occur from fluvial sources, coastal storm events or from inundation of coastal sites associated with sea level rise. Inundation can lead to contamination of a much wider areas associated with landfill leachate. These potentialities might require remedial action in the form of flood defence works.

Links with other Agency Functions

Activities regulated by other Agency Functions which may further impact on waste management activities through their responses to climate change will include:

- requirements under IPC, under which a number of process options for the management of waste are regulated;

- water quality requirements which will impact the management of leachate from landfills;

- leachate management techniques could be affected by water abstraction policy;

- flood control on coastal and fluvial sites can affect leachate levels.

6 RESPONSE OPTIONS FOR THE EMISSION REDUCTION AGENDA

6.1 MEASURES TO LIMIT GREENHOUSE GAS EMISSIONS

The UK, along with other countries, has developed a climate change programme and is revising this in the light of the Kyoto Protocol. 40% of the UK's total GWP lies with industries regulated by the Agency under IPC and a further 6% comes from methane emissions from landfill sites, also regulated by the Agency. The Agency will contribute to the climate change programme through its role as regulator and by influencing strategies.

In order to assess the carbon savings that the Agency can implement within its current roles and the potential for carbon savings from developing its roles, the Agency needs to be able to measure emissions accurately, monitor the carbon savings from mitigation strategies, identify any barriers to successful implementation of mitigation strategies, and assess different policy measures in order to target the most cost effective.

Assessment of different mitigation options will involve an assessment of costs and benefits. An intrinsic part of a full cost benefit analysis would take into account risk associated with mitigation measures that produce emissions reduction results over different time-frames. Risk may be reflected either as a premium on costs or as a modification in the discount rate applied to the analysis. The discount rate reflects the social rate of preference for consumption in the present period rather than in the future, and is taken to be 6%.(1) Whilst the discount rate is likely to be positive, it may be difficult to determine how it is affected by uncertainty, particularly when the potential consequences of climate change could mean significant environmental and financial costs. Thought should be given to how conventional appraisal models can be adapted to reflect risk and uncertainty.

In general terms, approaches to limiting greenhouse gases differ between gases and between the varied sources and sinks.

- CO_2 emission abatement can be achieved through changes in the *efficiency* with which fuels and energy are used by consumers and industry, or via *fuel switching* to less CO_2 intensive varieties - this might include switches from coal to gas for power generation but also replacement of fossil fuels with biomass energy(2) or other renewables.

- CO_2 can be *sequestered*, ie taken-up by the environment through an increase in the total stock of forests or timber products (or other biomass). It can also be *disposed* of or stored, for example, via liquefaction and subsequent

(1) HM Treasury, *Economic Approisal in Central Government*: *A Technical Guide for Government Departments*, 1991

(2) Biomass burning is regarded as having no net emissions of CO_2 because the level of emissions is equal to the quantity sequestered during the growing phase of the crop.

storage, although these measures are still largely at the research and development stage.

- For other greenhouse gases a range of *emission controls* are possible. These include end-of-pipe solutions (for example, pollution abatement equipment) or process change (for example, the introduction of cleaner technology). Methane reduction policies include, for example, regulations on gas recovery equipment for landfills, the reduction of leaks from fossil fuel production and transport facilities and the removal of organic waste from the waste streams going to landfill (as will be required under the Landfill Directive).

- All greenhouse gases can be tackled via *changes in consumption* patterns to less greenhouse gas intensive products or services.

There are a range of different types of policy measure that might be introduced in order to provide incentives for these different outcomes. They are made up of:

- cross-sectoral measures which are typically economic or market-based instruments such as carbon taxes. These can be used to provide an across-the-board incentive for a wide range of actions that could be taken in order to reduce emissions;

- targeted policy interventions directed at specific opportunities for emissions reductions such as improving energy efficiency in a specific sector or through fuel switching.

Economic instruments comprise a variety of measures which use market processes in order to achieve objectives. These include measures to change prices of goods or services, and those to develop markets where none currently exist. The two main instruments being discussed in the climate change context are carbon taxes and emissions trading.

Targeted measures include:

- regulations requiring specific actions or technologies, for example, energy efficiency or emission standards;

- subsidies to encourage specific actions, for example, for renewable electricity generation;

- information dissemination and leadership programmes as currently promoted by the Energy Efficiency Office;

- voluntary or negotiated energy efficiency agreements with firms;

- direct investment by government in technologies or other reduction measures.

6.1.1 *The UK National Programme*

The UK programme, included in the Second National Communication under the UNFCCC, sets out a range of policy measures that are currently being developed to address emissions of greenhouse gases, *See Table 6.1 and Box 6.1*.

Table 6.1 Examples of types of measures in each of the sectors

Sector/type of policy measure	**Supply side measures**	**Demand side management**	**Technological measures to reduce GHG emissions**
Transport	Increased public transport provision (local transport plans and measures). Safe provision for walking and cycling.	Land use policy to reduce transport demand. Fiscal measures (eg fuel duty escalator, company car tax, aviation fuel tax). Green transport plans (business).	Fuel efficient vehicles (CO2 targets for vehicles, labelling). Alternative fuel powered vehicles. Speed limit enforcement.
Energy	Changing fuel mix for generation. Promoting new and renewable energies. Promoting CHP.	Increased energy efficiency: - businesses through IPPC; - domestic through energy services providers. Fiscal Measures (fuel taxes).	Reducing leakage and transmission losses.
Agriculture	Promoting less intensive land uses (agri-environment). Reducing animal stocking rates. Encouraging afforestation Promoting energy crops on agricultural land.	Codes of good practice to reduce use of inputs. Market based instruments (charges or tradable permits for fertilisers).	Reducing livestock and animal waste emissions (extending IPC to pig and poultry production). Improving animal diet. Improving efficiency of refrigeration and cooling.
Public sector	Promoting CHP. Promoting more efficient energy sources.	Benchmark targets for building efficiency. Local Agenda 21 strategies with energy targets. Procurement policy in favour of high efficiency appliances and air conditioning. Development of Green Transport plans.	Encouraging development of energy efficient appliances.
Domestic sector	NFFO type scheme to promote CHP.	Building regulations. Energy efficiency measures: • cavity wall insulation; • other insulation. Fiscal measures.	Increasing market share of energy efficient technologies: • compact fluorescent lightbulbs; • energy efficient appliances.
Business sector	CHP. Promoting green electricity.	Energy efficiency (IPPC). Building regulations. Voluntary agreements on targets.	Measures to reduce leakage of other GHGs (leakage reduction targets; codes of

Sector/type of policy measure	Supply side measures	Demand side management	Technological measures to reduce GHG emissions
		Fiscal measures (industrial energy tax). Carbon trading.	practice; product standards).

Box 6.1 ***Categorising types of policy in the energy sector***

Supply side measures include those to change the fuel mix away from fossil fuels for power generation. Possible measures might include:

- removal of subsidies for carbon intensive fuels (ie coal);
- continuing to promote efficient gas fired generation capacity where social and environmental impacts are considered acceptable;
- continued reliance on nuclear;
- optimising the use of combined heat and power by setting a new target for 2010; providing advice, good practice examples and financial support to encourage take up of viable schemes; allowing exceptions to new, stricter consents policy for CHP; other measures (eg financial support);
- promotion of renewables through the NFFO with a target of 10% by 2010. Specific measures to promote renewables might include streamlining planning consents; encouraging R&D for new technologies (offshore wind and energy crops); encouraging take up of 'green electricity' opportunities by developing mechanisms for long term contract stability for suppliers.

Promotion of ***demand side measures*** to reduce energy demand might include:

- regulation of the utilities to include energy efficiency objectives;
- new energy efficiency Standards of Performance scheme;
- energy efficiency standards for business through the IPCC scheme; and
- energy efficiency for the domestic sector by encouraging the development of energy service companies.

Policies to ***promote more efficient technologies*** which reduce Green House Gas Emissions might include:

- continuing to promote combined cycle gas turbines, where appropriate; and
- minimising fugitive emissions and methane leakages through the promotion of IPPC.

The DETR released a discussion paper in 1998 on a strategy and possible policy options for emission limitation and reduction to meet Kyoto Protocol commitments. It discussed the main elements of the current emission reduction programme and listed a number of questions for consultees to consider. Responses are currently being analysed and will feed into the strategy.

The potential role of the Agency in limiting and reducing greenhouse gas emissions is addressed in the next section.

6.2 *POTENTIAL REGULATORY ROLE OF THE AGENCY IN MITIGATION*

The Agency has a significant potential role to play in mitigation policy because of the large proportion of total emissions that are emitted from processes licensed by it. This section discusses this potential role, including:

- the potential for BAT requirements under IPC;
- the potential for improvements in landfill gas capture;
- the possible role of the Agency in emissions trading and in environmental taxes.

6.2.1 *Integrated Pollution Prevention and Control*

The EC Directive on IPPC will be introduced between 1999 and 2007 and is the first piece of legislation to formally include consideration of energy efficiency in the UK. It extends the concept of IPC by requiring site operators to consider energy efficiency in addition to resource use, noise and site restoration for a particular installation. It is expected that guidance notes governing authorisations of intensive pig and poultry units for energy efficiency improvements and reductions in diffuse nitrogen emissions will be drafted. The purpose of the Directive is to achieve integrated prevention and control of pollution arising from defined activities, in particular through the application of BAT. The Directive requires competent authorities to ensure that regulated installations use energy efficiently and that energy use is taken into account when determining BAT.

All six greenhouse gases are currently prescribed substances under the Environment Protection Act 1990 which means the Agency can use the BATNEEC approach to control them. However, CO_2 is not a prescribed substance under IPPC. It is the new energy efficiency requirement which will be the important element determining the potential for IPPC legislation in controlling CO_2.

The Agency has already used its powers under the Environmental Protection Act to achieve very significant limitations to N_2O emissions from adipic acid manufacture. The DuPont plants are reducing emissions by 95% from a process that is a very significant contributor to total UK N_2O emissions. Other non-CO_2 greenhouse gases can be tackled in a similar way. The more interesting question at this stage is whether the Agency can use the licensing process to control CO_2 emissions and if it is appropriate for it to do so.

To date industry has paid little attention to CO_2 because of the absence of mitigation measures that can be taken at the plant level at reasonable cost. Technologies to capture and dispose of CO_2 (see *Box 6.2*) are developing and prices are falling. However, costs are still higher than many other options for reducing CO_2 emissions.

Options which the Agency might explore:

- energy efficiency requirements as allowed under the IPPC Directive;
- technology specification;
- offset requirements.

Box 6.2 Summary of CO_2 Capture and Sequestration Technologies

There are three basic approaches to the abatement of CO_2. The techniques are:

- Pre-combustion removal of carbon. This involves the de-carbonisation of fuel prior to combustion as hydrogen gas. Such an approach is being used by Norsk Hydro, and is well understood;
- In-combustion reduction of CO_2. This involves the recirculation of flue gases to reduce oxygen in combustion. This is the newest development in CO_2 mitigation and will become better understood over the coming years; and
- Flue gas abatement of CO_2. This involves a combination of membranes and solvents. Flue gases are passed alongside membranes that act as a barrier between gas and solvents. CO_2 can pass through the membrane and is dissolved in the solvent. The solvent can then be regenerated to release the CO_2. This CO_2 can then by shipped for storage.

While many of these ideas are experimental, a range of large scale demonstration projects are in place. Most researchers feel that these technologies will be commercially available in 5 or 10 years, and will cost approximately $2 - 20 per tonne of CO_2 reduced.

Once CO_2 has been captured it is necessary to sequester it. This can be achieved using two approaches:

- Geological approaches inject CO_2 into geological strata to aid the recovery of oil or gas or simply as storage. CO_2 is currently being used in the North Sea to enhance recovery of natural gas, and in Australia, US and Canada to enhance recovery of coal bad methane;
- Ocean approaches dissolve CO_2 into the oceans. This dissolving process either involves burying CO_2 in deep sea trenches as large bubbles or in piping CO_2 into the Ocean at 2 or 3 km depth.

Storage of CO_2 is currently costing $10 - 20 per tonne of CO_2.. This is however dependant on the shipping distance, either by boat or pipeline.

The Agency needs to understand its ability to control CO_2 emissions reduction within IPPC by:

- developing an accurate means for measurement of CO_2 and non-CO_2 emissions;
- analysing the potential for IPPC to address CO_2 abatement with different methods of implementation;
- developing an understanding of the various economic instruments available for implementation of emission control and their interplay with regulatory mechanisms such as IPPC.

There are some limitations to what can be achieved under this Directive, as it will apply in existing processes but not across the whole of industry; most small and medium-sized firms will be outside the scope of IPPC. IPPC will not in itself provide an incentive to switch to alternative approaches to CO_2 reduction.

Energy Efficiency

Under most circumstances there is a strong commercial incentive for running plants efficiently where there is sufficient knowledge about the technical options for doing so. Power plants will seek to maximise conversion efficiency in order to minimise production costs. However there will be many industries that are not aware of potential energy efficiency improvements which can be achieved through boiler management, refrigeration plant management and restriction of unnecessary leaks from compressed air systems. The Agency needs to evaluate energy efficiency gains it can plausibly expect from the industries it regulates.

The Agency will provide general guidance on energy efficiency relevant to all IPPC applicants which will set out the approach to energy management expected:

- operators must show that they have an energy management system in place, including the assignment of responsibilities for energy management and communication of matters of importance, good practice etc to staff;

- an understanding of energy usage on installations, the monitoring and targeting of energy;

- identification of activities where energy efficiency improvements can be made and a plan to improve efficiency.

The Agency intends to provide guidance to operators on the energy efficient measures that should be employed . On relatively simple decisions involving investment to improve efficiency, an approach may be to provide guidance on the basis of Net Present Value (NPV) of investment. Other decisions will have implications for releases of pollutants from the installation or elsewhere (for example, off- site generating plant) and NPV analysis may not capture all relevant factors.

The Agency will be preparing IPPC Guidance Notes for industry sectors to be regulated under IPPC. These will also provide guidance on industry-specific techniques. Other guidance for improving energy efficiency is being provided by the European IPPC Bureau, who are producing BAT Reference (BREF) notes for the industry sectors to be regulated under IPPC. The BREF Notes include energy usage data for key processes.

The Agency hopes that an additional means of influencing the behaviour of operators through IPPC will be through the reporting of results on energy usage and efficiency. The potential for adverse criticisms in the event of an operator comparing unfavourably with competitors may be a strong incentive for energy efficiency improvements.

An important issue for the Agency is to consider the trade-offs between energy use and controls of other pollutants, *See Box 6.3*. The Agency could usefully examine this trade-off in more depth, particularly the balance between requirements for Flue Gas Desulpherisation (FGD) under examples with and without use of low sulphur coal.

Box 6.3 Trade-offs between environmental objectives

An FGD plant has a major energy requirement (at Drax the FGD plant has an electricity demand equal to approximately 2% of Drax's output and running it drops Drax down the merit order). Running the FGD plant at Drax results in more than 400,000 tonnes of CO_2.[(1)] Therefore requiring additional SO_2 controls, eg beyond current requirements and future requirements under the revised Large Combustion Plant Directive and National Emission Standards Directive, has a clear trade-off with CO_2.

Addressing this trade-off requires a clear cost framework for assessing costs and benefits at the level of the wider economy: one of the costs of requiring FGD to limit SO_2 emissions is that CO_2 emissions will need to be controlled elsewhere in the economy (or the UK will have fewer surplus emission rights that might otherwise be sold abroad). Taking the Drax example, and assuming a marginal cost of CO_2 emission control of £10 per tonne, the costs are in the order of £4 million. There is, in addition, a process CO_2 emission (carry over or slippage) because flue gases react with limestone ($CaCO_3$) and produce CO_2.

However, £4 million is a small percentage of the total FGD plant costs and recent analyses of the benefits of SO_2 emission controls [(2)] suggest that the benefits greatly outweigh the costs. Using typical benefit data, adding a cost of CO_2 emissions is unlikely to suggest not installing SO_2. The benefit values are uncertain in these analyses however, and are dominated by health impacts particularly mortality effects.

For the Agency, the IPPC energy efficiency component presents some potential for reducing emissions of greenhouse gases, other than the responses already discussed, such as developing a role in providing guidance in the uptake of energy efficiency measures and energy efficiency reporting. While for large, energy intensive companies there is already a commercial incentive for energy efficiency, for others there may be a number of non-price barriers to the adoption of energy efficiency practices. In some instances a regulatory approach might be used to overcome these at low cost. In other instances, the costs of measures taken to improve energy efficiency must be weighed up so that low cost emission reductions can be achieved.

(1) This is based on 2% of current CO_2 emissions from Drax of 20.7 million tonnes (National Power. Environmental Performance Review, 1998)
(2) Environmental Resources Management (1997) *Revision of the Council Directive of 24/11/88 (88/609/EEC) on the Limitation of Emissions of Certain Pollutants into the Air from Large Combustion Plants: Cost Benefit Analysis of this Revision*. Report to the European Commission DGXI.

Successful implementation of IPPC requires detailed information about the technologies used, the emissions associated with these, cost effectiveness data for both end-of-pipe controls and pollution prevention measures. Environmental expertise and educated judgement will be required in order to balance the overall profile or releases to air, water and land.

Technology Specifications

BAT (or BPEO) requirements might be used to ensure efficient plant function by specifying what type of plant can be built. However, despite this example, the question remains whether the BAT concept can be extended to specifying what type of plant should be used for generating electricity, or whether it should only be used for best technology specifications for plants of a particular type. It is likely to be the latter.

Box 6.4 Trade-offs in BAT

One recent concern has been over the large number of applications for consents for Open Cycle Gas Turbine (OCGT) plants, rather than the more efficient Combined Cycle Gas Turbines (CCGT). This highlights the issue that there may in fact be a range of BATs for different modes of operation in the electricity market. CCGT will always be most efficient when operated at high utilisation, eg as a base load plant. However, in the other roles as mid-merit and peaking plant, OCGTs may in fact be BAT in terms of lower emissions per kWh. In these roles OCGT has the advantage of being able to switch on and off easily. Generating efficiency is maintained as most fuel burned is converted into electricity. In contrast, CCGT is not able to start up and shut down quickly, and therefore will continue to burn fuel in short periods where electricity is not required by the pool. The result is that the overall efficiency of the process decreases. Some modelling of this relationship has suggested that efficiencies could drop to be equivalent to OCGT.

Given the higher capital cost of CCGT compared to OCGT, for operation in mid-merit and peak roles, OCGT makes more sense on cost (and risk) grounds, and makes little difference in terms of efficiency.

Offsets

One approach, which has been used elsewhere for plant licensing, is the requirement for carbon offsets. In the US, offsets have been used to some degree for electricity producer bidding for supply contracts to electric utilities. In New Zealand, a recent decision under the Resource Management Act required a new CCGT plant to establish a forest to absorb the CO_2 produced from the plant or to reduce emissions elsewhere.

Current UK regulations provide no means for requiring such licence conditions as the licence applies to the installation only, defined as the site on which the plant sits.

6.2.2 *Waste Management Measures*

The Agency is responsible for regulating the treatment, storage and disposal of controlled wastes.

The UK's waste strategy, set out in the Government's White Paper, 'Making Waste Work', and reiterated in the 1998 consultation paper, 'Less Waste, More Value', adheres to the waste management hierarchy of waste reduction, re-use, recovery (recycling, composting or converting into energy) and finally disposal. 'Less Waste, More Value' promotes the BPEO as the most appropriate management route for wastes, but proposes the hierarchy as the starting point for its identification.

It is estimated that at present some 14% of municipal waste in the UK is recovered or recycled, with recycling running at some 7.5% of household waste. The Government has set a target of recycling (including composting) 25% of household waste by the year 2000.

By far the greatest proportion (70%) of controlled waste (excluding sewage sludge and dredged spoils) in the UK is currently sent to landfill. Some 80% of household waste is currently landfilled. In 1993/94 in England and Wales a total of 2,784 landfill sites were licensed, landfill being regarded as the only option for some inert wastes and for wastes that are difficult to burn or recycle. Some 45% of the total methane emissions in the UK are currently estimated as arising from landfills. This amounts to approximately 6% of the UK's global warming potential.

The Agency has recently published (draft) new guidance on the control of landfill gas which, if implemented, would require the installation of gas collection systems and high temperature (enclosed) flares at all landfill sites. Flare emission limits would be specified for a range of compounds.

Assuming that these, or similar, requirements are introduced, there will still be fugitive emissions of gas from the active working area of a landfill (area where waste is being deposited) prior to the installation of the wells and collection system but it should be possible to significantly reduce the amount of methane emitted from a site.

Estimates of the effects of gas collection measures vary. Meadows[(1)] suggests that the measures should be able to achieve an 80% capture of methane emissions by 2020. However, an 80% capture efficiency is higher than often achieved for new sites and is likely to be considerably higher than achievable from existing landfills. DoE,[(2)] for example, uses a landfill gas collection

(1) Meadows M (1997) Reduction of landfill methane emissions in: Phylipsen GJM, Blok K and Merkus H (Eds) *The Expert Group's work on EU Common and Coordinated Policies and Measures.* Netherlands' Presidency.
(2) Department of the Environment (1993), *Externalities from Landfill and Incineration.* A study by CSERGE, Warren Spring Laboratory and EFTEC. HMSO.

efficiency of 45%, and Aumônier,[1] uses a range of 48-72% for landfill gas captured over all time at a concentration high enough for combustion.

Capture efficiencies will increase as sites become progressively more highly engineered. For a well lined and capped landfill site, virtually all the methane should be being captured and converted to carbon dioxide via a high temperature flare or gas utilisation scheme. In addition to the escape of gas from the working area of a site (as discussed above), the main source of methane emissions will be from older sites where the rate of gas evolution has dropped to such an extent that it is no longer feasible to flare the gas. Although the rate of methane emission from a landfill at this stage is low, it continues for a great many years or decades. Thus, one way of reducing further national landfill gas emissions is the extension of gas collection and flaring systems to old landfill sites, or the engineering of sites when closed to encourage biological methane oxidation in cover soil.

Another waste management issue of importance to the management and control of greenhouse gases is sewage sludge disposal. England and Wales are relatively well sewered, with over 96% of the population connected to a waste water collection system in 1995. Some 80% of the population has its waste water treated to a secondary or tertiary level before it is returned to the environment. At present, the sludge arising from the treatment of this waste water is disposed of by three principal routes: by application to farmland; by disposal to landfills; and by incineration. Dumping at sea was formerly a major disposal route but is now illegal. From a greenhouse gas perspective, the major concern is over whether sludge decomposes aerobically (producing CO_2) or anaerobically (producing CH_4).

Minimising disposal to landfill, including pre-treatment by incineration, will be a key element of any emissions reductions strategy.

Together with the draft guidance on landfill gas collection and flaring, the Agency is taking steps to reduce the emissions of methane from landfills through initiatives such as:

- funding of research to give a better estimate of the total emissions of methane from landfills and the specific factors which affect the rate of emissions;

- commissioning of research into methane oxidation and its potential for reducing the methane emissions from landfills.

The Agency's key role will be in influencing the government's waste management strategy in measures to discourage disposal to landfill and the capture and use of landfill gas. In general, this is consistent with the current

(1) Aumônier, S. (1996) *The greenhouse gas consequences of waste management - identifying preferred options.* Energy Conversion and Management Vol 37, Nos 6-8 pp 1117-1122.

efforts of the Agency with respect to waste policy. Influencing the government's waste management strategy can be done through the promotion of life cycle assessment for waste management and the comparison of strategies for a range of environmental impacts, including greenhouse gases from all sources, including transport, energy use and recovery etc as well as methane from landfills.

The Landfill Directive will require the gradual reduction in the amount of biodegradable waste which is landfilled. This will reduce the methane generating potential of new landfill sites on a proportional basis. Increased incineration may result, increasing the opportunities for capturing energy from waste plants.

The ability to control methane would be better understood by the Agency through:

- assessing the potential to reduce emissions from landfills and other sources, highlighting the problem areas and identifying solutions;

- improving estimates of methane emissions and finding solutions to any difficulties in compiling accurate inventories.

6.2.3 Emission Trading

The Kyoto Protocol has established the principle that countries with national quantified emission limitation and reduction commitments can trade their emission rights or certified emission reductions with other countries. The rules for trading have not been agreed at this stage.

However, the Protocol highlights two approaches to trading:

- Trading of emissions rights under Article 17 of the Protocol.

- Project-based trading in which a project that results in emission reductions is used to create emission credits that can be transferred to another country.

Trading Emission Rights

Targets for greenhouse gas emissions limit the number of 'Rights to Emit' that are available at the national level. Firms could be given the responsibility for holding these rights in the form of emission permits in equal quantity to their actual emission rates within any budget period, for example, during 2008-2012. In aggregate, all firms would need to limit their emission rates to the number of permits available but permits would be traded in a way that ensured that they were acquired by those firms that valued them most, ie the firms that faced the highest cost for reducing emissions, *See Box 6.5* for discussions on allocation and trading issues.

Project-Based Trading

A project-based trading system involves the establishment of a project (for example, investment in new energy efficient technology) in one country and a calculation being made of the associated emission reductions. The verified reductions become a tradeable commodity which can be purchased by an entity within an Annex I country and used to add to existing emission rights, ie to increase the assigned amount.

There is some experience to date of this approach as a number of countries and firms have experimented with Joint Implementation (JI) or Activities Implemented Jointly (AIJ) projects. Typically these involve a firm in a developed country providing part of the investment capital for a project in another country (host countries have typically been in Central and Eastern Europe or Latin America and China) and a developed country technical partner that provides the equipment or technologies involved (for example, insulation, energy efficient products).

However, there is no reason why this is the pattern that needs to be followed. If the resulting emission reductions are a tradeable commodity, a wider range of firms will have an incentive to invest in order to create emissions credits in order to sell them on the international market.

The Kyoto Protocol establishes the means for project-based trading under Article 6-12, both amongst Annex I Parties, ie, countries with emission targets, and between Annex I and non-Annex I Parties (under the Clean Development Mechanism). However the mechanisms involved are different. Trade between two Annex I Parties is a bilateral arrangement between two countries with quantified emission commitments. In contrast, there is an incentive for cheating in trade between Annex I and non-Annex I countries since the non-Annex I countries do not have a limit on national emissions. Both buyers and sellers of credits will have an incentive to overstate the emission reductions from projects. These trades will be subject to international scrutiny and the Protocol has established the requirement for an Executive Board which will oversee the Clean Development Mechanism (CDM).

Verification is difficult for project-based trading where one trading Party does not have binding emissions targets. In order to demonstrate that an emission reduction has been achieved, it is necessary to develop a business as usual scenario to know what would have happened otherwise. For example, the project might involve:

- establishment of a gas-fired power station where there would otherwise have been a coal-fired plant. It is difficult to prove that coal would have been the technology of choice;

- introduction of energy efficiency measures, for example, a more energy efficiency boiler or insulation of a building.

Potential Role of the Agency

The Agency has a potential role in domestic implementation of the mechanisms, particularly with respect to monitoring industry emissions and enforcement of emission trades.

For Article 17 trading, ie trading in greenhouse gas emission rights, the monitoring task is to ensure that a legal entity (firm) that has a duty to hold permits to cover all of its emissions is in compliance with this. This involves establishing and using a mechanism for emission inventories at the firm or plant level rather than the more top-down approach that is used for national emission inventories, especially for CO_2. There will also be a potential role for the Agency in allocating emission permits. If emission permits are given to firms in proportion to some level of historical emissions (grandfathered) there will be a need for a record of historical emissions. There are a number of efforts being started to establish a pilot trading system in the UK. The Agency might contribute to these particularly in terms of their expertise in monitoring and enforcement issues.

For project-based trading, monitoring is required to guarantee the emission reductions from a specific project and, depending on the domestic rules set, some proof is likely to be required that the project is additional to what would have happened under a business as usual scenario.

6.2.4 Environmental Taxation

The March 1999 budget announced the introduction of a tax on the business use of energy, following closely the recommendations made by Lord Marshall in November 1998.(1) The taxes will not be set across the board, for example, energy intensive sites that agree targets for improving their energy efficiency will have reduced rates of tax levied on them.

The Agency could provide a role in the construction of emissions inventories, in order to monitor the effectiveness of the tax and to measure the compliance of energy intensive industries with their energy efficiency targets. This would help inform the government of the likely potential emission savings that might come from the imposition of the tax, ie, the reductions that are achievable and their cost.

It is likely that the energy tax will provide incentives for firms to install technologies that are energy efficient, thus responding to the energy efficiency component of IPPC. An optimal tax will be set at the level where the costs of

(1) *Economic Instruments and the Business Use of Energy*: A Counsultation Paper, 1998, Government Task Force on the Industrial Use of Energy

reducing energy consumption equals the environmental damage of emissions from energy consumption. The correct level of CO_2 mitigation will be taken up. In practice, there are factors other than efficiency that determine the level at which the tax is set. Nevertheless, the market can provide valuable information on the level and types of energy efficiency capital investment that the private sector adopts.

Whether the energy tax complements the IPPC mechanism will depend on the trade-offs between the reduction of different gases, *see Box 6.3*. The reduction of CO_2 may be at the cost of increasing other gases under the regulation. The dynamic effects from the use of an energy tax could also be limited by the over-specification of energy efficient techniques within the IPPC framework.

On the other hand, fiscal incentives could enable IPPC to become a more dynamic instrument that promotes process changes by encouraging consideration of future developments, through inclusion of conditions in authorisations requiring R&D into future solutions, and by going beyond the authorisations towards more ambitious negotiated solutions.

Flexibility in the way IPPC is applied will allow the Agency to learn how the tax impacts on technology investment, how it impacts on emissions of CO_2 and other pollutants and the environmental costs of different BAT configurations. Market information on the energy efficiency improvements that can be achieved, revealed through the tax, may be used to widen the boundaries of IPPC.

Box 6.5 *Allocation and Trading Issues*

Allocation: Permits can be allocated in a number of ways, based on historic emissions:

Grandfathering: permits are given to existing emitters based on some historic level of emissions.(1) This reduces the financial burden on these firms while still retaining the same economic incentives. However, the mechanism involves the gift of an asset to existing firms which will make it more difficult for new entrants to the market.

Auction: permits are sold to emitters. The government might auction the permits or place them on a domestic trading market similar to a commodities exchange allowing firms to bid against each other. This initial domestic allocation might protect UK firms from bidding from abroad. Alternatively, and given that permits will be internationally tradeable commodities, the government might place them on an international exchange or make permits available to overseas firms also. UK firms would need to bid against other firms in order to obtain their initial set of permits, but in a larger pool in which the permit price would equal some international trading price.

Who trades? Efficient trading on a government level trade requires governments to have a good understanding of the marginal costs of mitigation (cost curves) and therefore the value of permits. Many countries do not have cost curves or they are highly uncertain, largely reflecting the very wide range of possible mitigation options covering all sectors.

Amongst firms, trading can be at more or less aggregated levels. Traditionally permits for air pollutants (eg US sulphur trading) have been traded amongst final emitters, eg electricity generators. For CO_2 the system can be simplified. The principle that "carbon in" equals "carbon out" means that permits can be applied to the generators of carbon into the economy, that is, importers or producers of coal, oil and gas.

Most efficiently, permits would trade freely and could be held by anyone. Even if the responsibility to hold permits rested with carbon wholesalers, final emitters, eg power companies, may wish to hold permits to hedge against price fluctuations. These could then be exchanged with the fossil fuel supplier at the time that fuel was purchased. That said, it is unclear that power producers would choose to hedge against the risk of permit price fluctuation any more than other financial uncertainties.

6.2.5 *Combinations of approaches for environmental management*

IPPC and emissions trading are two fundamentally different ways of tackling emissions. IPPC relies on guidance or standards. Emissions trading uses the price system to allocate emissions reductions based on some overall emissions reduction target. The industrial installations regulated under IPPC would be obligated players in a trading system but participation in trading will be restricted if BAT requirements are interpreted in a narrow sense. For these reasons, the Agency might wish to consider how the three sets of policy measures could be combined. For example:

- allocation of pollution 'rights' could be allocated to obligated firms on the basis of historic emissions or some negotiated cap for a voluntary agreement. IPPC for energy efficiency simply acts as a backstop measure;

(1) By emitters we mean either final emitters or fuel wholesalers.

- site specific BAT assessments;
- generic BAT limits on a sector.

If BAT is used to decide the allocation of emission permits, it would be a logical extension of current IPPC responsibilities for the Agency to develop a role in determining what these allocations should be.

Voluntary agreements could complement IPPC, to encourage switches to different technologies. The ease with which voluntary agreements run in parallel with trading systems depends on the scale of monetary concessions agreed in the voluntary agreements. For example, tax concessions or grants in an agreement will give the industries participating in trading a dual benefit - benefiting from concessions in the agreement and also from monetary compensation from sales of permits. This will constitute unfair trading between sectors, and between firms in different sectors, as well as creating international market distortions in an international trading system.

The Agency can develop a role in relation to the development of renewable energy, particularly through its planning function. Developing a clear set of guidelines for weighing up the local amenity and other impacts of renewable electricity options with the wider global benefits of power generation will be a useful contribution.

6.3 POTENTIAL ROLE IN INFLUENCING STRATEGIES

6.3.1 Input to Government Strategies

The Agency has a very useful role to play in the development of government policy on mitigation of climate change impacts because of its technical expertise relating to the sources of emissions. This includes, in particular, energy emissions from large combustion plants, industrial emissions and landfill gas. The Agency is fulfilling this role in the context of interactions with government in the development of policy, through formal submissions to government policy documents such as the recent consultation paper on the UKCIP and through in-house energy efficiency improvements.

Setting an Example: Reducing its own emissions

The Agency is a large organisation and is thus a significant emission source through its use of energy for heating, lighting and running vehicles.

To date, the Agency has cut its own energy consumption by 20% compared to 1990 levels, following the UK's greenhouse gas emissions reduction target of 20% by 2008-2012. The Agency is currently investigating methods by which it is possible to procure part of its energy requirements from sustainable sources. The Agency is assessing the feasibility of generating hydro-electricity at

Agency sites, or using waste heat generated from such plant for use in its offices. Targets of a 5% reduction in business miles in 1998/99 and 7% in 1999/2000 have been set. Video-conferencing and options such as home working, the purchase of vehicles that run on alternative fuels such as Compressed Natural Gas and Liquefied Petroleum Gas and car sharing pools are being investigated. A further 10% reduction in energy consumption is currently being considered.

The Agency could identify an inventory of emissions from its own activities, noting the major sources, and identify managerial actions that might be taken to reduce these. Current actions include:

- investigation in the use of alternative transport fuels;
- measures to reduce use of electricity by its offices;
- investigation into the purchase or generation of green electricity;
- efficiency improvements in staff movements and other activities.

Box 6.6 Suggested Methodology for Developing an In-house Greenhouse Gas Reduction Plan

1. *Scoping*

Other organisations with a comparable range of activities and climate change impacts to the Environment Agency have considered developing greenhouse gas action plans. This involves a number of initial tasks such as:

- confirming which parts of the organisation should be involved (boundary setting);
- identifying which individuals are interested and should be involved; and
- developing a 'Framework for Action' (an outline of the Climate Change Action Plan).

2. *Greenhouse Gas Emissions Inventory*

A quantitative understanding of the starting position in terms of current emissions is important in the process of developing an Action Plan. It is suggested that the Environment Agency develop a straight-forward Greenhouse Emissions Inventory, including all sections of the organisation that are considered relevant, following recognised guidelines.

The proposed methodology was originally developed at Imperial College, advanced by the UN Environment Programme, before being taken over by the UK Department of the Environment, Transport and the Regions. Few organisations have yet implemented this methodology, and there is considerable scope to add in a carbon sequestration element to any proposed strategy.

With an agreed methodology the required steps are:

- data collection, including historical data where available, to identify trends (emissions reductions may be about reversing trends in the first few years);
- data collation;
- data transformation (into tonnes of CO_2 or carbon); and
- reporting.

3. *Planning Action*

There are three tasks involved in documenting the Action Plan, and these need to be undertaken simultaneously.

Target setting
This would be informed by the Agency's overall strategy and the Government's Climate Change Programme. It would be an iterative process that requires projections of emissions based on 'business as usual' or 'do nothing' scenarios, and projections of emissions reductions resulting from a range of possible actions.

Developing Actions
Actions would be considered in the context of sinks enhancements (sequestration initiatives) and emissions reductions in transport, energy use and type, and waste.

Inter-Agency Links
There are already a number of relevant initiatives within the Agency that will directly or indirectly lead to emissions reductions or enhancements of sinks. It will be necessary to:

- identify these;
- estimate projected net emissions reductions;
- identify any minor modifications to the initiatives that would increase net emissions reductions; and
- form links between the Climate Change Action Plan and the relevant business units.

4. *Communications*

The documentation of the greenhouse gas reduction plan will be an important symbol of the Agency's resolve to address the climate change issue. Perhaps, more importantly, it will be a valuable tool for internal and external communications.

It may also be relevant to consider training as part of an internal awareness raising exercise. Some actions within the Plan could involve staff in their normal roles and responsibilities. Internal awareness raising should accompany any such measures.

5. *Ongoing Monitoring*

The emissions inventory should be compiled on a regular basis as a means of assessing improvement. Results should be reported internally, and possibly externally, through a Sustainability or Environment Report.

The Agency could enhance the development of government policy for climate change mitigation in a number of ways:

- through providing a more detailed analysis of technical and policy options, for example, through the development of cost curves for technical options to reduce emissions. This has been partly undertaken in a number of projects for the DETR but there is no comprehensive and accepted set of cost curves for greenhouse gas mitigation in the UK;

- through the development of technology databases, for example, in support of regulated approaches to emission reduction.

The Agency can also have an important input to policy and strategy relating to energy. Most usefully this would be in relation to planning issues, particularly the issue of trade-offs between local disamenities relating to renewable energy and the global benefits of greenhouse gas emission reduction.

The Agency could develop an influencing role in the following areas:

- encourage the transfer of technology to developing countries;

- the potential for the Agency to encourage Resource Demand Management (RDM) to encourage energy conservation and efficiency improvements;

- encouragement of carbon free renewable energy sources.

6.3.2 Technology Transfer

The UK government, along with other developed countries party to the UNFCCC has a commitment to the transfer of technology to developing countries and to assist them in developing their own capacities to respond to the greenhouse gas mitigation agenda. The Foreign Commonwealth Office (FCO) has recently announced a fund to encourage transfer of climate change technologies between private companies in the UK and developing countries. The Climate Change Challenge Fund, as it is called, will make use of British expertise in clean technologies and renewable energies. The private sector is expected to match public sector funds in technology transfer projects.

To date, very few countries have responded to this commitment in a way that has been deemed satisfactory by the developing countries. Largely this is because there is much confusion over what technology transfer entails and because governments that have the commitment do not own the technologies. Other efforts being taken by countries relate to the exchange of information on technologies, for example, through the development of technology databases, or through training in new technologies.

Agency staff have considerable expertise in technologies that would be relevant in many other countries and could usefully contribute to the UK’s efforts in technology transfer in association with other departments and international organisations including the Climate Technology Initiative, set up by developed country party to the UNFCCC.

6.3.3 Resource Demand Management

In addition to supply-side measures to reduce emissions, including improvements in efficiency of transformation of energy, emission reductions can also be achieved through action on the demand side. The Agency could take a more active role in this area through existing initiatives such as the Energy Savings Trust or through extending its role into an advocacy one. For greenhouse gas emissions this would include energy efficiency, energy conservation measures, waste minimisation and decreased use of road transport. The Agency does not employ specialist staff in energy efficiency and would need to do so if it were to take on any sort of advocacy role

Box 6.6 Partnership Approaches in Energy Efficiency

The Energy Savings Trust and other related organisations are already set-up to encourage demand management measures to encourage energy efficiency and conservation. In its climate change consultation paper, the government supports the development of a partnership of all those with an interest in promoting domestic energy efficiency such as central and local government, retailers, manufacturers, installers, energy suppliers, consumer organisations and agencies concerned with energy efficiency. This partnership would be facilitated by the Energy Savings Trust.

Although the Agency does not have a clear role in household energy efficiency and conservation, consumption of high energy demand products needs to be discouraged. Information that is needed before action such as this is considered as a way forward are the level of carbon savings achievable from the domestic sector, the possible carbon savings that could be captured from different demand management measures and an assessment of those which the Agency could usefully collaborate on with existing bodies in this area.

6.3.4 Renewable Energy Sources

In the longer term, if the UK is to make the significant reductions in emissions that are required carbon-free energy sources will become increasingly important. This will involve a shift in the fuels used for electricity generation and a shift towards greater use of electricity as a heat and energy source for industrial, commercial, domestic and transport sectors. Currently, carbon-free energy sources include renewables and nuclear power; it is estimated that they will constitute 4% and 26% respectively of power generation in the UK by 2000.(1)

The government is committed to encouraging more renewable energy. Its review of renewable energy policy looks at what would be necessary and practicable to deliver 10% of UK electricity demand from renewables by 2010. The review also looks at longer term potential; it is considering existing mechanisms such as the Non-Fossil Fuel Obligation and other possible programmes.

(1) Climate Change. The United Kingdom Programme. The UK's Second Report under the Framework Convention on Climate Change. 1997.

The *New and Renewable Energy Programme* and the EU's *White Paper on Renewables, COM(97)599 final* both emphasise the potential for substantial growth in the amount of energy generated from biomass including energy crops, forest residues, poultry litter and crop residues. Short rotation coppice is currently the most suitable energy crop for UK conditions as it is capable of being grown productively on both arable and reasonable quality pasture land. It has one of the highest energy yields and development is well advanced. Current review of renewable energy policy is considering what contribution energy crops might best make to meeting climate change and renewable energy targets, and looking at options for funding. Policies that encourage the planting of energy crops need to be sensitive to other environmental issues, such as biodiversity and landscape effects.

The Agency's role in respect of renewables is most clearly seen with respect to planning issues and particularly the trade-off between local amenity and other disbenefits associated with renewable energy and the greenhouse gas reduction and other benefits at the national and international level. The Agency could usefully contribute in assessing the trade-offs between planting energy crops and the costs accruing to other environmental resources.
Clear guidance on this trade-off would be a useful contribution to the implementation of renewables policy.

Nuclear power plays an important part in helping the UK meet its climate change targets. The climate change consultation paper suggests that it should continue to contribute to UK emission reductions, provided that high standards of safety and environmental protection are maintained. However, other environmental and economic factors need to be taken into account when considering a longer term role for nuclear energy. In the short term the Agency might develop its own means for weighing up the risks versus the climate change benefits.

6.3.5 Other potential measures

The Agency could also take an active role in encouraging the uptake of other policy options recommended in the UK emissions reductions national strategy, including:

Building regulations

The energy used in the operation of buildings themselves accounts for 40-50% of the UK CO_2 emissions, half of which comprises commercial and industrial buildings. It is suggested that building regulations may be extended in scope, both requiring more stringency in some areas and extending their coverage. There is clearly a role here for developing best practical standards or benchmarks for different types of buildings and for measuring emissions, monitoring and enforcing regulations. Progress across the public and private sectors could be assessed and any modifications could be fed back into the standards.

Treatment and use of non-CO_2 gases

Codes of practice for non-CO_2 gases may be drawn up, as well as the design of non-CO_2 gas leakage reduction targets. The introduction of registration and training of users and manufacturers of non-CO_2 gases has been suggested.

Utility regulation

The Agency could contribute to, or carry out, the social and environmental regulation of utility regulators, who could be placed under a duty to have regard to the energy efficiency guidance in the exercise of their functions.

Small and medium enterprises

Most small and medium enterprises (SMEs) are unlikely to have dedicated resources or technical expertise in energy or environmental management. They are also unlikely to be covered by existing regulation and face low energy costs as a proportion of their total overheads. Thus it is likely that significant carbon savings could be captured from this sector. The exact potential for CO_2 reductions and also non-CO_2 reductions from small and medium sized firms should be investigated. Standards of energy performance could be drawn up.

7 ADAPTATION RESPONSES FOR THE AGENCY TOWARDS THE IMPACTS OF CLIMATE CHANGE

7.1 AN INTEGRATED APPROACH

One of the important elements in the development of an adaptation strategy for the Agency is that of the interaction between functions. In particular, fisheries, conservation, navigation and recreation have a very close relationship with all other functions of the Agency and meeting the duties in each of these functions will be made possible in large part, if not all, from the actions taken in other functions.

In order to balance the pressures and duties of all Agency functions, and in recognition that the actions of one function may impact on another, a management or appraisal technique is needed in order to determine optimal levels of resource use and thereby maximise social welfare from consumption of environmental resources. Input into an appraisal technique might be obtained from sources such as the recent work carried out examining the benefits of water use(1) which is helping to clarify which are the groups most affected by changes in water quantity and quality. They include direct users of the river (anglers and boat users) but also picnickers and walkers plus "non-users", ie those who benefit from knowing that the river is there and retain an option to visit it.

The following information is organised under two distinct headings:

- *strategic responses*: the information / model / assumptions that should be made as a basis for identifying responses;
- *response options*: the tools that can be used to deliver results and limits in what can be realistically achieved by them.

The following assessment is intended as a general overview of response options and the sorts of issues determining such response options.

7.2 WATER RESOURCES

7.2.1 Strategic Responses

At present, in state-of-the-art models of future climate change, it is not yet possible to make reliable predictions of climatically-induced changes in supply and demand for water. There are large uncertainties in climate scenarios at the space and time-scales required for impacts assessment. Further uncertainties arise in the translation from climate change to impacts on

(1) Foundation for Water Research (1996) *Assessing the Benefits of Surface Water Quality Improvements*. Manual FR / CL0005.

water resources due to hydrological model structure, uncertainties in the direct CO_2 effect and changes in land use. Nevertheless, climate is likely to change and associated with this change will be increasing temperatures. Historical evidence and modelling studies indicate that water supply and demand are highly sensitive to climate variability / change, although the absolute direction of the changes is uncertain.

To date, most of the work on climate change and water resources has focused on trying to quantify the potential impacts on supply and identify particular critical thresholds or sensitivities. Much less work has looked at the actual implications of what is, essentially, an increase in the level of uncertainty in future supply and demand. To provide advice for the actual management of water resources it is necessary to look at the existing mechanisms for coping with uncertainty on short (management) and long (investment) time-scales and assess whether the threat of increased uncertainty due to climatic change is great enough to warrant action now and, if so, what type of action is most appropriate.

The general consensus of climate impact studies is that because of the high level of uncertainty in the impacts of potential future climate change on supply and demand, it is not yet necessary to take action on the grounds of climate change alone. For projects with long lead times and design-life, however, it may be prudent to consider the potential effects of climate change alongside other driving forces which will affect water resources management in the future, such as increasing demand from urban, agricultural and industrial sources, technological change, changes in land use and so on. For instance, studies such as Conway *et al.*(1) show that the potential implications of climate change for water resources may be much less than those due to population growth, changes in demand for water and changes in economic priorities for the allocation of water.

Kaczmarek *et al.*(2) emphasise that most studies to date have simulated impacts in the absence of adaptation to change. In practice, however, water management systems will begin to adapt to gradual change. This is already taking place in the British Isles as authorities respond to the impacts of the anomalous climatic periods of the 1980s and 1990s.(3) For instance, a desalinisation plant is under construction in East Anglia.

Water resources management is inherently designed to deal with future uncertainty. This is achieved through five interrelated approaches:(2)

- new investment for capacity expansion;

(1)Conway, D. and Jones, P.D. 1996 *Production of Precipitation Scenarios for Climate Impacts in Europe.* Final Report. European Community Environment Research Programme (contract: EV5V-CT-94-0510). Climatic Research Unit, 50pp.

(2)Kaczmarek, Z. 1996 *Water resources management in Climate change 1995: Impacts, adaptations and mitigation of climate change.* Scientific and technical analyses. Contribution of working group II to the second Assessment Report of the IPCC. *Watson, R.T., Zinyowera, M.C. and Moss, R.H.* (Eds.) Cambridge University Press, Cambridge, 469-486.

(3)Palutikof, J. P., Subak, S. & Agnew, M.D. eds., 1997b: *Economic Impacts of the Hot Summer and Unusually Warm Year of 1995.* Report for the Department of the Environment, University of East Anglia, Norwich, 178pp.

- maintenance of and rehabilitation of existing systems;
- operation of existing systems for optimal use;
- modifications in processes;
- demand-side management.

Use of Scenarios in Water Resources Planning

Because climate change is uncertain there is an emerging move towards the use of scenario based approaches to estimating impacts. Scenarios of climate change differ in the nature and level of impact across different sectors but the assumption is that each scenario is equally probable.

Water companies have been allowed to make an allowance for climate change in the current periodic review. The Agency has produced guidelines on how to take account of climate change in water resource planning and have suggested use of Arnell's four scenarios *(see Annex A).* These have been used by some water companies during the current periodic review (AMP3). However, the incentive for the water companies is to be risk averse and to use the scenario which suggests the greatest possible water supply deficit.

Risk and uncertainty generated by climate change also needs to be incorporated into Agency planning time frames for large projects such as reservoir construction, and the planning of certain demand side management measures. Climate change adds another important dimension to the objective of achieving the sustainable use of water resources.

7.2.2 Response Options

Responses to changes in the demand for and supply of water resources will be focused on water abstraction rates, bulk transfer arrangements, efficient operation of resources and demand management measures. New water resources will be developed only if these measures provide 'insufficient scope to meet properly managed demand'.[(1)]

Abstraction Licences

The Agency's power derives from its licensing role. Granting new licences requires consideration of the need for water, the impacts on other abstractors and regard to other lawful users of water resources, including the environment. Virtually all new abstraction licences are time-limited. Under a revised system of water abstraction licences in 1999,[(2)] existing licences will be converted to a

(1) Environment Agency, 1997 *Saving Water, Taking Action: The Responses to the Consultation Report on Water Conservation and Demand Management*
(2) Ends Report, April 1999

time limited basis. Abstraction Management Strategies will be established alongside LEAPS. Abstraction Management Strategies will outline the status of water resources in each catchment and will be used to inform the Agency's licensing policies.

15 years has been suggested as the limit for licences although a specific period of time will not be legally prescribed. The Agency will have the discretion to grant longer time limited licences for water abstraction schemes involving major infrastructure. It is envisaged that compensation for the removal of water abstraction licences will be abolished from 2012. Previously excluded water abstraction activities, such as non-spray irrigation, will be included in the new system.

During drought conditions, the Agency has powers to grant drought permits, which give water companies the power to restrict water supplies. It also has the power to limit water abstraction for spray irrigation during periods of drought.

A move to time-limited licences goes some way to ensuring that abstraction licences reflect water scarcity. Decisions must be made about which user groups should benefit from water abstraction in periods of increased scarcity. Decisions made on the basis of price allow those who value water most highly to pay to have their allocation of water unchanged or increased. Equity issues are important to consider, especially for the lower income groups where the negative income effects would be highest.

One method of using the price system is through implementation of a trading system for abstraction licences. The quantity of trading licences on the market will reflect the target level of water available for abstraction. This target level in the future will be influenced by the measures taken to develop water resources, which will, in turn, reflect the climate change scenarios used as a planning basis by the Agency.

The domestic sector water pricing should encourage sustainable use and should reflect both financial and environmental costs, while ensuring continuity of supply to vulnerable groups.

Frequent assessments of the Abstraction Management Strategies and the review of abstraction licenses will allow the incorporation of information of climate change impacts as it emerges, particularly information on impacts at more localised levels. It also allows time for learning about the 'optimum' levels abstraction for all catchment areas, taking into account the duties and demands for water of other Agency Functions.

Demand Management

In addition to controlling levels of supply via the abstraction licensing system and inputs to decisions on capital supply works, the Agency is currently addressing the overall volume of demand using measures such as:

- water conservation practices in its own activities;
- requirement of full cost benefit analysis of demand management measures alongside an abstraction licence application;
- development of local leakage targets for water companies;
- supporting research on tariffs that are environmentally effective;
- development of educational material;
- trial of grey water recycling facilities;
- action to reduce over-abstraction at Sites of Special Scientific Interest (SSIs);
- ensuring that water companies develop and implement plans to secure essential supplies.

Demand predictions are somewhat uncertain and the effect of certain demand management measures, for example, educational measures, may take effect over the longer-term, with uncertainty of their effectiveness. An optimal package of demand measures, and their interaction with other response strategies, would need to be flexible to reflect these uncertainties. Monitoring of demand trends and water savings associated with different demand measures would reveal information on the effectiveness of different demand side management responses.

7.3 WATER QUALITY

7.3.1 Strategic responses

Water pollution

For emissions from waste water treatment plants, the responses of firms are dependent on Office of Water Services (OFWAT)-approved capital expenditure within the five-yearly periodic reviews. Waste water treatment plant design specifications are based on dry flows with maximum flows often 25% higher than this. Plant design may need to change in the face of possible higher storm water flows.

Water companies are allowed to charge for water and waste water treatment in order to repay capital expenditures on the basis of a 7% discount rate and 30-year lifetime. There is evidence that much shorter time frames are used for commercial investment decisions. Water companies would need to re-specify their plant, within the overall spending cap, or as agreed by OFWAT, within a subsequent periodic review. Internalisation of climate change impacts requires a greater time frame than required by these periodic reviews. Although private costs will be recouped if additional capital works are approved by OFWAT during the normal periodic review process, society's costs will be higher if investments are found to be lower than they should optimally be to recognise climate change.

The issue of the trade-off between the effects of additional pollution control requirements on waste water treatment plants and the maintenance of stream flows is an important issue for the Agency to address in examining the implications of policy options to maintain and enhance water quality, see *Section 5.6.2* for further discussion of the possible closure of small waste water treatment plants. More specifically, what is more important: more streams or larger cleaner ones?

7.3.2 *Response options*

Actions that will be taken with regards to water quality and will be affected by the impacts and uncertainty of climate change include:

- review and where necessary revise the charging for discharges scheme;
- develop an Agency National Plan for Water Quality;
- develop an Agency strategy for the control of eutrophication;
- develop approaches to the assessment of costs, benefits and risks.

The primary means of controlling water quality is through discharge consents issued by the Environment Agency. The Agency may set conditions relating to places and periods of discharge, volume and rate, and the nature, origin, composition and temperature of the discharges. These conditions are in turn determined with reference to Environmental Quality Standards (EQS) which establish concentrations of specified substances. Discharge consents are determined almost exclusively on the basis of environmental modelling of the effects of the discharges and some consideration of the costs of abatement (the principle of BAT). The environmental modelling must be adapted to incorporate the uncertainties and impacts of climate change, and the changes in river conditions. For example, changes in precipitation rates throughout the year might determine when discharge consents should be given in order to maintain a certain flow level in rivers.

Detailed water quality planning at a catchment level is an established practice being taken forward within LEAPs. Building on this approach, an Agency National Plan for Water Quality will be developed for the maintenance and future improvement of water quality. This should take into account the impacts of climate change on other functions, their response, and their corresponding impact on water quality. This entails two levels of uncertainty to be internalised in the planning process.

There is little that can be done about enhanced eutrophication associated with an increase in temperature, but a strategy for the measurement and control of eutrophication could seek to reduce nutrients input to water bodies from agricultural chemicals and waste water as well as maintaining and increasing water levels in rivers in order to dilute nitrate concentrations. Higher treatment standards for waste water treatment plants could lead to a consolidation of waste water treatment plants that reduces water flows in certain rivers. On the other hand, high standards of treatment of effluent would ensure that fewer nutrients are released into river water. The relationship between eutrophication and temperature changes is complex and dependent on numerous variables including photosynthetic pathways, food chain interactions, diurnal temperature fluctuations and sediment and nutrient inputs. An understanding is needed of the most significant sources of eutrophication, their interaction and the effects of altering different parameters for design of an effective eutrophication limitation strategy.

The Agency has released a consultation document for a proposed strategy for managing eutrophication.(1) In it the Agency proposes encouraging public and government collaboration, establishing criteria for prioritising water for eutrophication management, setting water quality targets and proposing the development of Eutrophication Control Action Plans (ECAP). ECAPs will be produced as a result of the LEAP process. The Agency is drawing together details of the best available methods, models, techniques and procedures for the development of ECAPs. A number of response options is identified in the consultation document.

7.4 *FLOOD DEFENCE*

7.4.1 *Strategic response*

The UK has a long history of interventionist protective measures to protect land from flooding and coastal erosion. Much experience, especially in the fields of hard engineering, has been gained in coastal protection methods. As a result a culture of expectation has risen that resources should be spent to protect coastal developments. Individuals and localised interest groups, in areas where coastal zones are already suffering losses to the sea, can exert

(1) Environmental Issue Series 1998, *Proposed Management Strategy for Eutrophication*
http://www.environment-agency.gov.uk/ourservices/consultations/aquatic.htm

considerable political pressure in diverting national resources into coastal protection. In reality, there are stringent criteria for funding capital schemes, and schemes have to achieve a high economic benefit. The cost ratio may need to be as high as 4:1 to achieve a high priority for funding.[(1)] It is estimated that the shortfall in expenditure needed to ensure that the Agency's inland and sea defences are maintained and, where necessary, restored is between £30m and £40m.[(2)] Intensified pressure for construction on flood plains, conservation requirements under, for example, the EU Habitats Directive and impacts deriving from climate change add to further pressure for coastal protection.

MAFF produces guidelines on the preparation of shoreline management plans (SMP), which develop strategic plans for a specified length of coast, taking account of coastal processes, human and other environmental needs, and existing defences. Four generic options are available for each management unit: 'do nothing', hold the existing line, advance or retreat. Economic viability of the strategic options should be assessed through an analysis of the benefits and costs. Any strategic coastal defence option must be sustainable and evaluated in economic, engineering and environmental terms. The options which are acceptable should then be tested against the objectives set against the preparation of SMPs and developed SMPs. The options are then ranked.

Climate change potential has implications for this strategic planning process. A level of uncertainty is added to the evaluation of data for coastal processes, which is compounded by the long term time frame over which climate change impacts develop. One of the objectives for the preparation of SMPs is the prediction of likely future evolution of the coast, as the basis for establishing the economic viability of the strategic options. Uncertainty will mean that comparisons between the benefits of strategic options may not be representative of the true benefits to be achieved by some sea defence options. Lower cost benefit ratio options may be screened in if climate change impacts are greater than expected. Another objective in the preparation of SMPs is to identify all the assets within the SMP which are likely to be affected by coastal change. A good understanding of the links between different natural and human resources is needed in order to evaluate all costs and benefits involved. The Agency could improve understanding of the links of different resources under its responsibilities.

IPCC identifies three basic policy options, which future policy would probably combine:

Retreat

Retreat can range from minor realignment to provide additional flood protection, to the abandonment of land and property in areas where, under

(1) Agriculture Committee Sixth Report Flood and Coastal Defence, Volume 2 - Memorandum submitted by Middlesex University Flood Hazard Research Centre, 1998.
(2) Agriculture Committee. Sixth Report *Flood and Coastal Defence* The Stationery OFfice, 1998

existing levels of protection, loss through erosion and / or flooding is relatively imminent. 'Managed retreat' includes active measures to resettle displaced persons, to discourage further development and to change existing land uses, for example, from agricultural to saltmarsh. Among the advantages of retreat is a reduction in the interference with natural processes, some of which would feed back into a strengthening of natural coastal protection. For example, if, through abandonment, supplies of coastal sediment were increased, some coastal zones would actually benefit where accretion results in development of new beaches or saltmarshes.

Accommodate

A wide range of adaptation strategies would allow for continued use of areas which are at risk, but perhaps not the very high risk areas. Adaptive strategies would include measures to increase protection of existing infrastructure with co-ordination and planning at relatively local level. With co-ordinated planning facilitated by increased knowledge of coastal morphological dynamics, natural processes and thus natural coastal defences would have an increased chance of being maintained. Bray *et al.*[(1)] list several fronts where modelling work will enhance knowledge of coastal processes thus improving the prospect of success from co-ordinated planning.

Protect

The implication here is a comprehensive protection of vulnerable areas, particularly those of high economic value. The solutions used would tend to be conventional, high cost, hard engineering including embankments, sea walls and tidal barriers. Such schemes require details of relative sea level rise, thus the need for accurate projections relating to localised geological movement and to (thermally induced) sea level rise. Whilst effective schemes would assure protection for lengthy time horizons, consideration of the effects on natural processes may well take second place.

Bray *et al.* give a detailed listing of policy strategies (over 100 year timescale) and include guidelines to applicability with some discussion of the advantages and disadvantages of each. These guidelines also include 'soft' engineering options for coastal protection, based on the use of naturally occurring features or processes, (such as water meadows and natural floodplains), in a controlled manner, to beneficially supplement or replace flood defences. However, the encouragement of 'natural' features can be a costly financial option but may, at the same time, provide amenity value.

[(1)]Bray, M.J.,Hooke, J.M, & Carter, D. 1997: *Planning for sea-level rise on the south coast of England: advising the decision makers.* Transactions of the Institution of British Geographers 22, 13-30.

7.4.2 *Response options*

Risk analysis

There are considerable uncertainties in estimates of all of the factors of importance, viz rates of sea level rise, level-frequency curves, frequency and magnitude of extreme events. However, within this context, the Agency has to demonstrate that the benefits of measures taken to combat flooding justify the costs. With climate change impacts on flood risk, the expected benefits of flood alleviation schemes will increase. The extent to which average annual damage is adjusted each year is dependent on how flood risk is assessed. Even with current data, risks are handled in a relatively simplistic way.

MAFF is in the process of modifying its guidance on risk analysis for flood defence measures, moving from a deterministic towards a probabilistic approach. This would lead to a different type of decision model in which decision makers are more concerned with addressing "what if" scenarios.

This approach is consistent with a move throughout the Agency towards more risk-based approaches to management and planning, supported by the establishment of their National Centre for Risk Analysis and Options Appraisal. The Agency and MAFF are working closely together in the development of these risk-based approaches.

Planning and Guidance

The other response approach is through the planning process and provision of advice regarding location of settlements and other land uses on flood prone areas. The risk analysis techniques discussed above are important here.

One of the most important elements of the Agency's inputs to the planning process is the production of flood hazard maps. These are produced infrequently and are expensive to compile but there is the potential for them to be immediately out of date under a dynamic climate system in a state of continual change. There is, however, a level of uncertainty attached to the maps, which are in themselves approximate. Generally, planning authorities work with the Agency in interpreting flood risk. The issue of out-of-date maps will be an internal issue for the Agency in keeping regional staff aware of changing impacts.

Producing more accurate flood maps and extending the size of existing flood plains raises important issues concerning public information and associated impacts on the housing sector from the increase, or withdrawal of insurance from risky areas. The creation of 'blight' areas may reduce development pressure in flood plain areas, affecting Agency Functions.

The impacts of fluvial flooding will depend on the physical characteristics of specific catchment areas. Socio-economic impacts will depend critically on location of settlements on flood plains and other land uses. A system that assesses the impacts of rates of change of sea level rise on flooding risk for tidal rivers and estuaries may be provided by the Catchment Management planning under the Water Framework Directive.

The development of a manual for taking account of climate change for river planning along the lines as that developed for benefit valuation of river works by the Foundation for Water Research (FWR) may be useful.

Flood Forecasting

It is likely that climate change will increase the frequency and severity of extreme events. Better flood forecasting systems are needed. Although there are improvements underway for finer resolution meteorological models and research on factors affecting flood risk such as the effects of sea bed topography, there are limits to flood forecasting. There is still likely to be a level of uncertainty associated with flood warnings. Public perception of Agency competency will depend on the frequency of flood warnings. In addition, the potential economic losses will create pressure to improve flood defences. Simultaneous flood events in a cluster of regions weakens the possibility to pull adjacent regional resources together. Better planning for flood events is needed.

A prioritisation of flood warning schemes based on the vulnerability of people potentially affected by the floods would enable the Agency to decide where to direct resources.

7.5 CONSERVATION

7.5.1 Strategic Options

One of the most important elements of a conservation strategy will be to come to a better understanding of the concept of what should be maintained. Should the Agency seek to protect:

- ecosystems and habitats in their original (pre-climate change) state;
- naturalness, ie allowing ecological change in response to climate change but ensuring that whatever the ecosystem, it is “natural” for that location and climatic condition, given minimal anthropogenic interference; or
- what people like.

Resolving or debating these issues would enable the Agency to better contribute towards decisions on biodiversity management in the short and long term. This is important for both implementation of the Habitats Directive and the likely implementation of the future Water Resources Framework Directive.

7.5.2 *Response Options*

Current response tools and actions for conservation include the following:

- *Regulation:* applications for Agency's consents and licences are screened for impacts on wildlife or landscape;

- *Best practicable environmental standards* when carrying out Agency work such as flood defence measures or restoration of river habitats;

- *Research* focusing on evaluation methods, conservation criteria for Agency authorisations and management requirements for those habitats and species included in Action Plans.

- *LEAPs:* ensure that aspects of the UK Biodiversity Action Plan are integrated into Agency guidance and LEAPs .

Potential productivity increases on currently marginal areas may require planning measures to conserve patterns of land use.

Climate change will occur too rapidly for some species to adapt in an evolutionary sense. Measures that ease the migration of species, such as provision of habitat corridors and the translocation of species may be needed instead. Special attention could be focused on those areas that are particularly vulnerable to climate change such as the wetlands in Southern England, coastal marshes and montane communities.

It is important to maintain the collection of baseline environmental data to monitor change and allow ongoing adaptation of management practices to the changing environment.

There are a range of organisations with a primary responsibility for conservation and biodiversity, including DETR Wildlife Division, English Nature and the Countryside Council for Wales. All are participating in activities to develop a better understanding of the impacts of climate change on wildlife and biodiversity. The Agency is participating in these activities to gain a better understanding of impacts, for example, via the UKCIP.

7.6 *FISHERIES*

7.6.1 *Strategic response*

The Fisheries Function are currently considering information on the potential climate change impacts on water resources and water quality. To achieve integrated river basin management, the Function must pursue research and learning initiatives that:

- help define ecologically acceptable river flows to protect fish stocks and fisheries;
- identify potential impacts (and mitigation) of changing land use and rainfall patterns on key habitats, such as salmonid spawning gravels;
- determine ecologically acceptable levels of sub lethal components of discharges such as endocrine disruptors.

Other Agency Functions will need to take account of this information in the determination of their response strategies.

There is a need for a robust evaluation of the social and economic benefits accrued from inland fisheries in England and Wales in order that they can be defended against the future challenges associated with climate change impacts such as changes in availability of water resources.

7.6.2 Response Options

Tools to control the fish populations include control of net fishing and control of fishing gear, habitat restoration, fish passes, control of disease and re-stocking.

There are a number of options which might be required over the longer term:

- oxygenation, for example, using bubblers (although this is energy intensive);
- additional fish-stocking;
- reduction in fishing season;
- reductions in availability (increased price) of trout and salmon licences.

The Function should develop and disseminate best practice for fishery managers that provides options for a sustainable response to the projected climate change.

Long-term monitoring of the fish communities will enable changes to be identified and allow the benefits from adaptive management approaches to be evaluated.

7.7 RECREATION

It will be difficult to predict the needs and demands made by resident and visiting populations to recreational facilities even in a situation of climate stability. What seems certain is that recreational demand will increase, and that it is essential for the Agency to maintain the opportunities for increased leisure.

Managing the water resource to meet the differing objectives of a number of competing users will be an important aspect of the Agency's fulfilment of this function. At this stage the most important strategic response by the Agency is developing a better decision making process for priority setting with respect to multiple users of scarce resources, particularly waterways.

In order to avoid increased emissions from private car use resulting from greater recreational demand, it will be important to provide accessible and attractive recreational opportunities close to where people live. This may require improved opportunities to access and enjoy rivers, lakes and reservoirs in and around inland towns and cities in order to dissuade people from travelling to the coast.

7.7.1 Response options

The Agency delivers its greatest contribution to its recreation duties through the work of its other functions. Maintenance (and enhancement) of river flows, river and lake water quality as well as coastal resources such as beaches is necessary in order to maintain recreational sites. Recreational improvements may be made as part of flood alleviation schemes which improve local amenity with landscaping, footpaths, seating and interpretation. Structures such as weirs and sluices can be modified to improve conditions for white water canoeing. The Agency will need to respond in a dynamic way to these changing pressures over time.

7.8 NAVIGATION

7.8.1 Strategic response

The Agency is seeking to further develop the inland waterways as an integrated network. Its ability to achieve this will be affected by water abstraction decisions and flood control investment. A way must be found to minimise loss of water or impact on other objectives whilst maintaining and increasing the navigational use of waterways. Managing these competing water uses will be an increasingly challenging issue.

7.8.2 Response Options

Navigation responsibilities are managed as an integral part of the river management process. This ensures that all water demands are balanced against the capacity of the environment to meet these demands. Currently navigation in periods of low flow can be maintained through management of locks and weirs, for example, keeping boats back at locks during periods of low flows until several go through together.

The actions of the Agency on its navigations therefore has wide repercussions on the waterways network and the considerable recreation and tourism industry which depends upon it. The Agency will therefore be constrained in the ways in which it will be able to react to situations; it will not be able to act in isolation. Collaboration is sought with other Agency functions, and also local authorities who have a key role in the planning system. Management techniques that co-ordinate different river users in a sustainable manner need to be developed.

The Agency is party to the recently published National Strategy for Inland Waterways, produced by the ssociation of Inland Navigation Authorities (AINA) of which the Agency is a member. The Agency's actions in relation to navigation should be decided within that context.

7.9 ENVIRONMENTAL MONITORING

Indicators of climate change impacts will be needed to characterise the potential changes which could take place on a global and UK scale. To investigate the effect these impacts have upon environmental media such as water resources and ecological systems will require the systematic collection of data sets over a long time scale at appropriate reference sites.

The Department of Environment, Transport and the Regions launched a set of climate change indicators in May 1999. These cover a wide range of possible impacts and include environmental indicators ranging from temperature trends to groundwater levels to flood gate closure frequencies to bird nesting times. A number of these indicators cover environmental resources that are managed by the Agency. The Agency needs to determine its role in the monitoring of these indicators, and in the collection and interpretation of data. This will be of particular importance for water resources and flood defence who directly manage a few of the DETR indicators such as frequencies of closure of the Thames Barrier.

The Agency might wish to develop its own additional climate change indicators to give a more comprehensive picture of the consequences of climate change for the UK environment, and in particular the environmental media managed by the Agency. The Agency should undertake an investigation of the changes that may be required to its monitoring systems in order to effectively monitor long-term changes in the environment.

In particular the Agency should examine the scope it has to make unique contributions to the measurement of impacts, for instance through the deployment of its remote sensing systems to examine physical change such as coastal erosion and chemical/biological change such as those resulting from increasing eutrophication of water bodies.

8 HOW SHOULD THE AGENCY MOVE FORWARD ON THE CLIMATE CHANGE ISSUE?

8.1 RESPONDING TO CLIMATE CHANGE IN THE UK

Developing a climate action plan should include both mitigation and adaptation strategies. The high emissions reduction targets facing the UK in the context of Kyoto Protocol, and existing evidence on the level of 'safe' emissions, emissions reduction is clearly a priority. Emissions mitigation is addressed in *Section 6*. The severity of potential impacts and the long term nature of the planning process means that developing an approach to dealing with the likely impacts of climate change on some areas of the Agency's day to day business also needs to begin in earnest. This is addressed in *Section 7*.

8.2 THE STRATEGIC QUESTIONS

The Agency has recognised that climate change is an important (some would argue the most pressing) environmental issue for the Agency and indeed for the environment of England and Wales. There are many challenges involved: the issue is clouded in uncertainty, there is a relatively poor public understanding of its complexities and there are numerous other organisations involved.

There is no clear agenda for moving forward but it is important that this is not taken as a reason for inaction. In addressing a suitable agenda for action, we have structured our discussions around a number of principles:

1. Take the Initiative.
2. Work with Others.
3. Maintain Credibility.

8.3 TAKE THE INITIATIVE

There is a risk that the environmental effects associated with climate change will happen more rapidly than anticipated. And it is clear that climate change will not involve a smooth transition to a new climate equilibrium. There will be surprises. These have the potential not only to damage the environment but also to damage the Agency's standing.

"Wait and see" and being reactive to events will be acceptable in some areas, but is not overall an adequate response. The Environment Agency both wants to and needs to be prepared to cope with the likely changes that are ahead.

However, this is more helpful advice where the problem is clear and the solutions are limited. For climate change, our knowledge of the likely effects is expressed only in the form of a number of scenarios of possible future outcomes, and even these are highly uncertain, involving as they do the down-scaling of model results from averages over geographically widespread areas to local outcomes for specific geographical features. In these circumstances, taking the initiative might involve:

- monitoring and research;
- emissions reduction;
- adaptation.

8.3.1 *Monitoring and Research*

This research project has brought together some of the most recent findings of research on the impacts of climate change on the issues of interest and concern to the Agency. But it is by no means comprehensive nor does it seek to be a detailed review of all the issues that will need addressing in coping with future changes. The Agency will need to do more to ensure that it is adequately informed of the likely future effects building on the most recent research. Developments at regional level will be important.

The UKCIP provides the best forum for the Agency to explore this and to develop collaborative research programmes with a number of other organisations. For decision makers such as the Agency, it would be useful to develop a set of extreme scenarios, for instance of the likely impacts on water availability, as a tool for developing a range of possible managerial responses to “what if” questions.

The Agency, with its extensive remit and ability to monitor the environment, is also in a key position to develop programmes which can measure the actual effects of climate change and how these may relate to model predictions. This is particularly the case with regard to the effects of storms on beaches, where the Agency has to take action in relation to flood defence, and with regard to its role in monitoring changes in eutrophication of inland and coastal waters.

Developing “impact scenarios” would be a useful contribution of the Agency to UKCIP and would assist the Agency in taking the initiative in the development of appropriate and adaptive managerial responses.

8.3.2 *Reducing Emissions*

Reducing emissions of greenhouse gases is being pursued under a national climate change programme consistent with the FCCC and its Kyoto Protocol. However, the targets set for the period up to 2012 are clearly only a first step in a much more ambitious programme that will be required over the longer term. The Environment Agency has a number of possible options.

The strategic question for the Agency concerns the way it should move forward and the role it might play in helping to shape the UK’s emission reduction strategy. *Table 8.1* summarises the roles which the Agency could play, in three main ways:

- *improving the carbon balance* of its own activities by developing a Climate Change Action Plan. The approach to developing such a plan is described in more detail in *Box 6.6.*

- *directly influencing* private sector emitters of green house gases through its role in the IPPC process. The Agency is in the position to integrate energy efficiency and CO_2 emissions into the IPPC and BAT process. This will, however, require some further work in developing methods of measurement and monitoring of green house gases, and for comparing the technical and economic trade-offs between different technologies, particularly in the energy sector. The monitoring and enforcement role could extend to the use of economic instruments such as energy taxes and emissions trading;

- *indirectly influencing* or contributing to UK Government policy affecting climate change emissions (renewables and technology transfer programmes) and consumers (through awareness raising initiatives). These indirect actions would involve extending the interpretation of the Agency's current roles and responsibilities.

Advocacy

The Agency has chosen climate change (including the causes and potential impacts) as one of its nine themes. Yet it is clear that the forces driving the UK's contribution to atmospheric greenhouse gas concentrations are complex and well beyond the Agency's powers to control. Nevertheless, it appears that in seeking to honour the holistic approach of its Environmental Strategy the Agency is showing an interest in having a greater influence beyond its statutory duties regarding options to reduce greenhouse gases. If it were to develop this role, either in the context of advocacy within the government decision making process, or in the public domain, there are two options:

- building on the issues for which it has some current expertise based on its current activities, for example, advocacy of waste minimisation in order to encourage the reduction of greenhouse gas emissions from landfills;

- developing into a more broad-based advocacy organisation as a means for achieving its broad environmental objectives identified under its Environmental Strategy, for example, in promoting particular renewable energy sources, and / or energy efficiency and reduced transport use.

It is easier to justify the Agency's activities under the first category. However, sustainable development lies within the realms of the Agency's statutory duty through education of industry and the public on the broad lifestyle and economy changes, needed to reduce greenhouse gas emissions to the necessary level. It is important that activities undertaken under the latter category are done in the context of the national climate change programme.

Table 8.1 Responses Options for the Agency to Reduce Emissions of Greenhouse gases

Issues	Comments	Response Options
Improve carbon balance of Agency's own activities.	Requires a Climate Change Action Programme.	Emissions reduction measures: • energy efficiency targets for buildings; • demand reduction measures (eg for transport); • green procurement to reduce emissions of other GHGs (eg green electricity, refrigeration and cooling equipment); Carbon sequestration measures: • supporting tree planting on Agency owned land and in relation to other government initiatives (eg community forests).
Options for directly influencing other players		
IPPC	The main elements of IPPC relevant for climate change are: • integration of energy efficiency in the application of BAT; • involvement of small firms not under IPPC; • assessment of energy efficiency along with other BAT requirements.	• develop understanding of policy measures and their interaction; • develop methods for accurate measurement of greenhouse gases; • develop methods for measurement and reporting on energy efficiency; • develop assessment mechanisms for net costs of different pollutants; • development of a strategy for demand side management in energy efficiency in conjunction with existing measures.
Economic instruments	Two possible approaches to trading imply different roles for the Agency: • project based trading; • trading of emission rights.	***Taxation***: monitoring of efficiency of tax and impacts on investment behaviour. Can be used to inform the IPPC process. ***Project based trading***: • monitoring emission reductions in relation to business as usual for specific projects, important for proving additionality. ***Emission rights trading:*** • allocation of permits; • monitoring and enforcement of emission trades; • establish mechanism for emission inventories at plant level.
Options for indirectly influencing other players		
Influencing government policies with an impact on climate change.	Climate change provides the EA with an opportunity to develop its role in the formulation of UK environmental and waste management policy.	Enhance role of the Agency from technical expertise in emissions sources to expertise in emissions reduction through: • detailed analysis of technical and policy options to reduce emissions; • development of technology databases; • develop strategy for discouraging waste to landfill and encouraging/ improving techniques for capture and use of landfill gas.

Issues	Comments	Response Options
Technology transfer to non-Annex 1 countries.	The government has a commitment to technology transfer, as part of the UNFCCC.	• contribute to FCO / DTI initiative on technology transfer for climate change to developing countries together with NDGB and CBI.
Renewable energy.	The government plans to increase the use of renewable energy from 4% in 2000 to 10% in 2010.	• develop guidance on planning issues such as the trade-off between costs and benefits of renewable energy; • develop guidance on the assessment of risks of nuclear power and the benefits of CO2 reductions.

8.3.3 Adaptation

The regional and sectoral impacts of climate change will pose threats and opportunities to many sectors and organisations, including the Agency. The actual effects will be highly localised and at this stage uncertain in terms of severity and timing.

While climate change impacts challenges the Agency in fulfilling its objectives across all functions, the Agency is in a far stronger position than most organisations to plan for and adapt to expected changes at both a strategic and practical level.

At a strategic level the Agency needs to recognise that there is a 'cascade' of uncertainty in climate impact analysis. This begins with uncertainty in projections of future greenhouse gas emissions and consequent climate change scenarios. Further uncertainty is involved in 'down-scaling' to the finer scales required for impact studies. Translating climate changes to, say, changes in river flow involves further uncertainty due to differences in the design and structure of hydrological models and because their parameters are tuned to present day climate and therefore may not be representative of future conditions. For all these reasons, actual change will be remain difficult to predict. In addition to trying to reduce uncertainty through more detailed impacts research it will be important for the Agency to develop decision tools for dealing with uncertainty.

Because of the all-pervasive nature of the issue for the Agency's functions, a response strategy will need to reflect a hierarchy of priorities. Not all of the issues need a strategic response now. For some areas, the immediate response will be developing decision making techniques. For others, immediate action will be required, particularly in managing conflicts between competing users of scarce resources. For several areas such as air pollution and fisheries the strategy may be to 'wait and see' while for others the Agency is already taking actions consistent with likely future changes.

Because of the level of uncertainty, engineering solutions with respect to the impacts of climate change are likely to be inappropriate in most instances. Where engineering solutions are required for other reasons, for example, flood defence works, taking account of the likely impacts of climate change is clearly a wise response consistent with the precautionary principle. But in most instances, the best response will be in ensuring that decision making can be more adaptive to likely future changes in climate and its effects, for example, shifting towards time-limited water abstraction licences.

Table 8.2 summarises the issues and some of the adaptive measures which might be considered by the Agency.

Table 8.2 Adaptation Responses to Climate Change by Function

Function	Impacts	Response
Water Resources.	• water availability may well decline in southern England; • uncertainty in water supply will increase.	• develop risk-based analytical techniques for dealing with uncertainty in climate scenarios; • development of mechanisms for the allocation of water; • demand management actions; • integration of emergent information on water availability into the Abstraction Management Strategies.
Water Quality.	• increased biological activity and nutrient levels leads to decreased oxygen levels; • greater leaching into rivers; • increased frequency of low flows; • flooding of sewage treatment facilities; • increased soil erosion; • increased incidence of algal blooms.	• ensuring maintenance and increase in river flows; • encouraging decreased use of agricultural chemicals; • input into land use policy; • modification of conditions relating to discharge consents; • change in waste water treatment plant design specifications; • develop a National Plan for Water Quality; • develop a strategy for the control of eutrophication.
Flood Defence.	• sea level rise & increased frequency of storm events means more frequent breaching of flood defences; • increased run-off & winter stream flows (all year round in north) may lead to more river floods.	• development of risk-based analytical techniques to address flood risk decision making; • work with other organisations, eg insurance industry, to help develop understanding of risk and consequences for society; • public communication of risk and nature of impacts; • increased efforts into monitoring and detection of flood risk to reduce uncertainty; • increasing robustness of flood warning systems.

Conservation.	• movement in species and shifts in the suitability of current sites for protecting species.	• develop internal understanding, working with other organisations, to agree on a conservation strategy, using tools currently available to the function and through integrated planning of river management in other functions.
Fisheries	• water temperatures and flows will be adverse for salmon & trout; • possible changes to ocean currents will affect fish life cycles and survival.	• research must define acceptable river flows; • impacts from land use change and rainfall patterns on key habitats should be identified; • define acceptable levels of sub-lethal discharges into rivers; • develop a robust evaluation of costs and benefits of fisheries; • long-term monitoring; • 'best practice' response guides for fisheries managers; • integrate fisheries objectives into the planning process of other functions for an integrated approach to river management.
Recreation	• changes in the demand for and supply of recreational sites; • increased emissions from increased car use in the pursuit of leisure opportunities.	• maintain and increase opportunities for recreation through input into the planning actions of other functions and LEAPs.
Navigation	• increased frequency of low flows; • increased incidence of storm events affects the navigability of waterways; • increased temperatures should accelerate vegetation growth affecting waterways.	• maintain and increase opportunities for navigations through input into the planning actions of other functions and LEAPs.

8.4 WORK WITH OTHERS

There are a number of organisations currently involved in policy and other activities to manage the risks associated with climate change.

8.4.1 Mitigation

The overall national programme is coordinated by the DETR and it will be important that the Agency works closely with DETR in helping to deliver that programme. Given that the Agency regulates close to 50% of the aggregate of emission sources, it should become more involved in the development of policy responses. This includes building on the Agency's technical expertise in emission controls and process efficiency but also having an input to decisions regarding appropriate policy responses, for example, the potential role of emissions trading as a component of the national mitigation strategy. Because of the international nature of the climate change policy response, this may involve the Agency becoming involved both at a European and international level in developing these policy ideas.

8.4.2 Impacts and Adaptation

The national response to climate change will involve all sectors of society and it will be important for the Agency, in developing its strategy, to work with a wide range of these other organisations. The Agency will need to build and maintain consensus with the users of the resources that it manages wherever possible. This may involve working closely with other organisations to develop an understanding of the impacts of climate change using mechanisms such as jointly sponsored research.

8.5 MAINTAIN CREDIBILITY

Taking the initiative on adaptive measures needs to be carefully balanced with the need to maintain credibility in responding to uncertain information.
The uncertainties associated with climate change mean that in many cases actions to deal with climate change may have very real costs but uncertain benefits. In instances where there is pressure for new housing, the choices of available land may be between green belt or flood plain areas. Emphasising the risks of flooding under climate change in the planning process may lead to greater use of green belt land with associated environmental damages. Climate change might, on the other hand provide greater impetus for using brown field sites.

The Agency faces some risks in responding to the climate change agenda, particularly because of the large uncertainties that surround the issue. For instance the flooding of 1998 and resultant damage to property and resources has been a source of some criticism of the Agency. No one is certain that these anomalous conditions are attributable to climate change. In such circumstances there is a risk that the Agency:

- will be blamed where it has not anticipated outcomes that are the result of climate change;

- blames climate change unjustifiably to cover up management failure.

Actions to reduce climate risks will involve financial costs which will also need to be justified. The Agency needs to develop a clear and transparent decision making approach that enables the weighing up of risks, costs and benefits associated with climate change as it affects the range of functions and resources that it manages. This is likely to require the Agency to work more with scenarios of the possible impacts of climate change (as noted above) and to use these to ask “what if” questions relating to many of its functions.

There are a number of external messages that the Agency will need to give:

- There is a need for a much clearer message from the Agency regarding our current understanding of climate change. The vast majority of scientists are unwilling at this stage to ascribe any specific event to climate change; rather that recent temperature and other climate anomalies are consistent with climate change. The Agency needs to assist in raising the understanding throughout society of climate change and its potential impacts on the UK.

- Agency management concerns for issues such as flood management and water abstraction, may be heightened by the uncertainty associated with climate change. Awareness and understanding of emergent information on climate change impacts will be important in the strategic management of these resources.

Annex A

Climate Change Projections

A1 CLIMATE CHANGE PROJECTIONS

A1.1 MODELLING FUTURE CLIMATE CHANGE

A1.1.1 General Circulation Models

Coupled ocean-atmosphere GCMs are mathematical representations of the time evolution of the global climate system. Model calculations are based on the laws of physics and executed at widely spaced points of a three-dimensional grid at a resolution of approximately 5° by 5° latitude and longitude (the versions of the Hadley Centre GCM referred to in this study operate at 2.5° by 3.75° resolution). *Control* experiments are run to simulate current climate ($1xCO_2$) and two methods can be used to estimate the response of future climate to greenhouse gas forcing: *equilibrium* response and *transient* response.

In equilibrium mode, the GCM is run with an abrupt increase in CO_2 concentrations, usually a doubling from 300ppm to 600ppm, referred to as $2xCO_2$ equivalent ('$2xCO_2$'). The difference between the $1xCO_2$ and the $2xCO_2$ climate at each grid point is then used to represent the equilibrium climate change due to a doubling of atmospheric CO_2.

Transient experiments involve coupled ocean-atmosphere GCMs. These are run over a control period to simulate the current climate (and to ensure the ocean and atmosphere reach a steady-state). Gradually increasing radiative forcing (representing increased concentrations of greenhouse gases) is applied over time to provide a time dependent transient response of the climate system - more realistic than a '$2xCO_2$' experiment. It is results from recent transient experiments performed by the Hadley Centre for Climate Research that are used in this report.

Up until the early 1990s most GCM simulations had been equilibrium experiments, providing a scenario for a time when the climate system has reached a balance with a given increase in greenhouse gas concentrations.

A1.1.2 How much change? Global

Figure A.1 and Figure A.2 [(1)] show the time evolution of global mean surface air temperature and sea level out to 2100 based on the latest IPCC estimates and incorporating the effects of sulphate aerosols. Both estimates have a range of uncertainty associated with them due to the value of climate sensitivity and the future rate of emissions of greenhouse gases. Climate sensitivity refers to the steady-state increase in global annual mean surface air

[(1)]Raper, S.C., Viner, D., Hulme, M. and Barrow, E. 1997 *Global warming and the British Isles. In Climate of the British Isles, Present, Past and Future.* Ed. by *M. Hulme and E. Barrow.* pp 326-339.

temperature associated with a given global mean radiative forcing. This has been quantified by calculating the change in global mean temperature resulting from a doubling of CO_2. It ranges from 1.5° to 4.5°C with a mid-value of 2.5°C used by the IPCC as a 'best guess'.

Figure A.1 ***Global Warming Projection from 1990 to 2100 using a Simple Climate Model, assuming the IS92a Emissions Scenario and Three Different Values of the Climate Sensitivity***

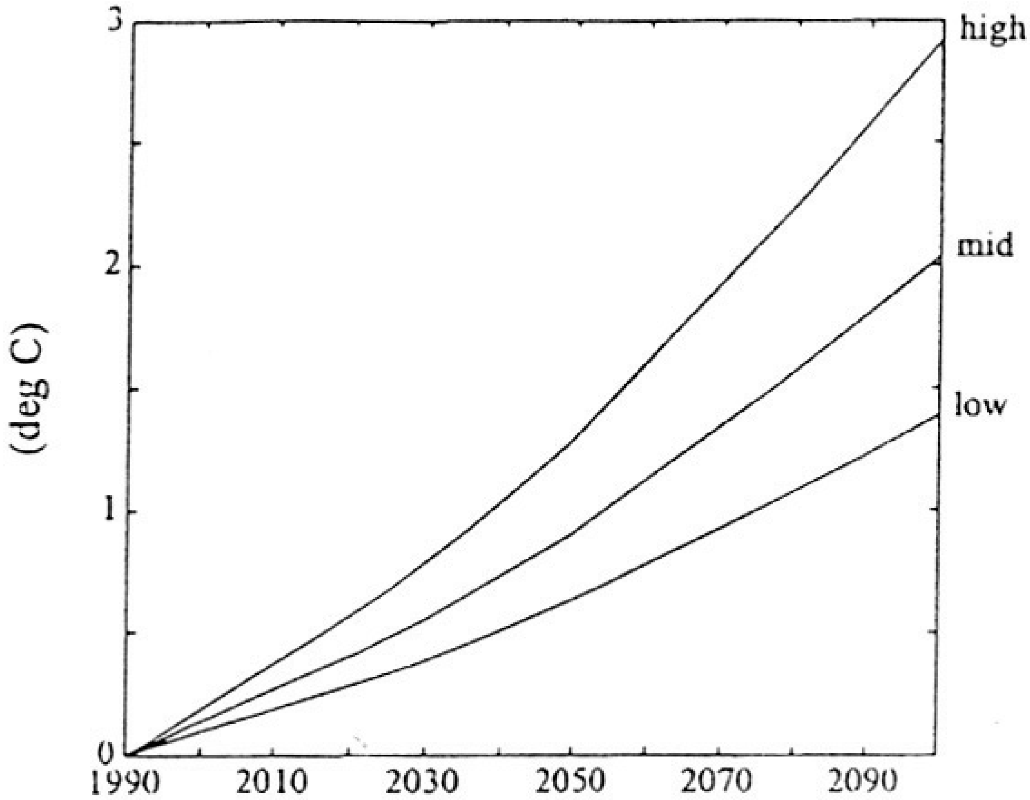
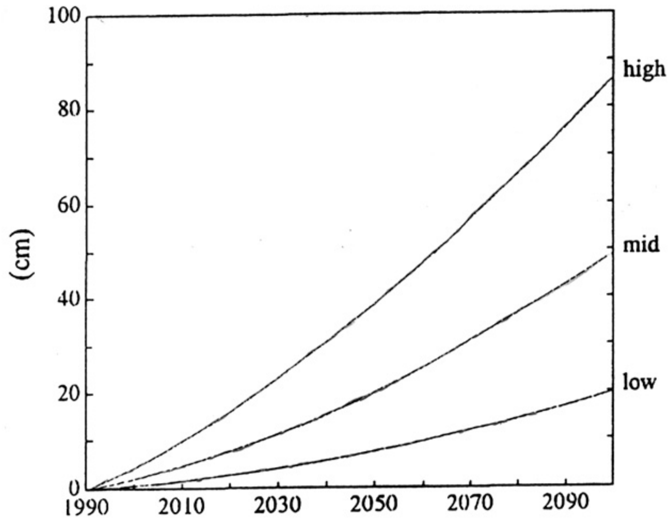


Figure A.2 ***Global Sea-Level Rise Projections from 1990 to 2100 Using a Simple Climate Model, Assuming the IS92a Emissions Scenario and Low, Mid and High Settings for the Climate and Sea Level Parameters***



To account for the uncertainty of future emissions of greenhouse gases, the IPCC developed six scenarios, IS92a-f, based on assumptions concerning population and economic growth, land use, technological changes, energy availability and fuel mix over the period 1990 to 2100 (see *Table A.1*). The uncertainty of the magnitude of the climate sensitivity and the range of emission scenarios produces the following range of increase in global annual mean surface air temperature:

- a lower limit of 0.8°C by 2100 with climate sensitivity of 1.5°C and IS92c (lowest emissions); and

- an upper limit of 4.5°C with climate sensitivity of 4.5°C and IS92e (highest emissions).

Table A.1 Summary of Assumptions in the Six IPCC 1992 Alternative Emission Scenarios

Scenario	Population	Economic	Growth (%)	Energy Statistics
IS92a,b	World Bank 1991 11.3 billion by 2100	1990-2025: 1990-2100:	2.9 2.3	12,000 EJ conventional oil 13,000 EJ natural gas Solar costs fall to $0.075 / kWh 191 EJ of biofuels available at $70 / barrel[a]
IS92c	UN Medium-Low Case 6.4 billion by 2100	1990-2025: 1990-2100:	2.0 1.2	8,000 EJ conventional oil 7,300 EJ natural gas Nuclear costs decline by 0.4% annually
IS92d	UN Medium-Low Case 6.4 billion by 2100	1990-2025: 1990-2100:	2.7 2.0	Oil and gas same as IS92c Solar costs fall to $0.065 / kWh 272 EJ of biofuels available at $50 / barrel
IS92e	World Bank 1991 11.3 billion by 2100	1990-2025: 1990-2100:	3.5 3.0	18,400 EJ conventional oil Gas same as IS92a,b Phase out nuclear by 2075
IS92f	UN Medium-High Case 17.6 billion by 2100	1990-2025: 1990-2100:	2.9 2.3	Oil and gas same as IS92e Solar costs fall to $0.083 / kWh Nuclear costs increase to $0.09 / kWh

Source: IPCC, The Supplementary Report to the IPCC Scientific Assessment: IPCC Emission scenarios for IPCC: an update, 1992

In spite of the wide range of warming rates in all the cases, the average rate of warming would probably be greater than any seen in the last 10,000 years.

Uncertainty in rates of sea level rise range from:

- 15cm by 2100 with IS92c emissions (low) and low climate and ice melt sensitivity; up to

- 95cm by 2100 with IS92e emissions (high) and high climate and ice melt sensitivities.

In spite of the agreement between GCM results, however, large uncertainties remain in the estimation of future emissions and concentrations of greenhouse gases, rates of biogeochemical cycling and the representation of climate processes in models (particularly feedbacks associated with clouds, oceans, sea ice and vegetation).

A1.1.3 *How much regional change?*

There is much greater uncertainty in making projections at regional scales because of the following uncertainties:[(1)]

- Coarse resolution of GCMs prevents realistic representation of many geographic features, vegetation and interactions between the atmosphere and land surface which may be important on regional scales.
- Greater natural variation in local climate than in climate averaged over continental or larger scales.
- Regional impacts of aerosols on climate.
- Changes in land-use and land cover as a result of climate change may influence temperature and precipitation, especially in lower latitudes.

At best, these scenarios are plausible and physically consistent descriptions of a future climate.

A1.2 *FUTURE CLIMATE SCENARIOS FOR ENGLAND AND WALES*

A1.2.1 *Recent results from the Hadley Centre for Climate Prediction*

The methods of deriving climate scenarios from GCMs have been reviewed comprehensively in the literature. *Figure A.3* shows a framework for the construction of climate change scenarios from the results of GCM experiments.[(2)] Over the last couple of years, results have become available from a number of experiments performed by the Hadley Centre using a modified model (known as the HADCM2) derived from earlier versions [(3)] . These results supersede those of previous scenarios produced for the British Isles, such as the Climate Change Impacts Review Group scenarios (CCIRG, 1991 and 1996). The Hadley Centre has performed a number of experiments to investigate future climate change as follows.

1) A 1000 year control run (*CON*) with no changes in external forcing (with CO_2 fixed at the pre-industrial level of 280 ppmv) in order to simulate present day climate.

[(1)]Houghton, J.R., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. and Maskell, K. (eds.), 1996 *Climate Change 1996: The Science of Climate Change,* Cambridge University Press, Cambridge 572pp.

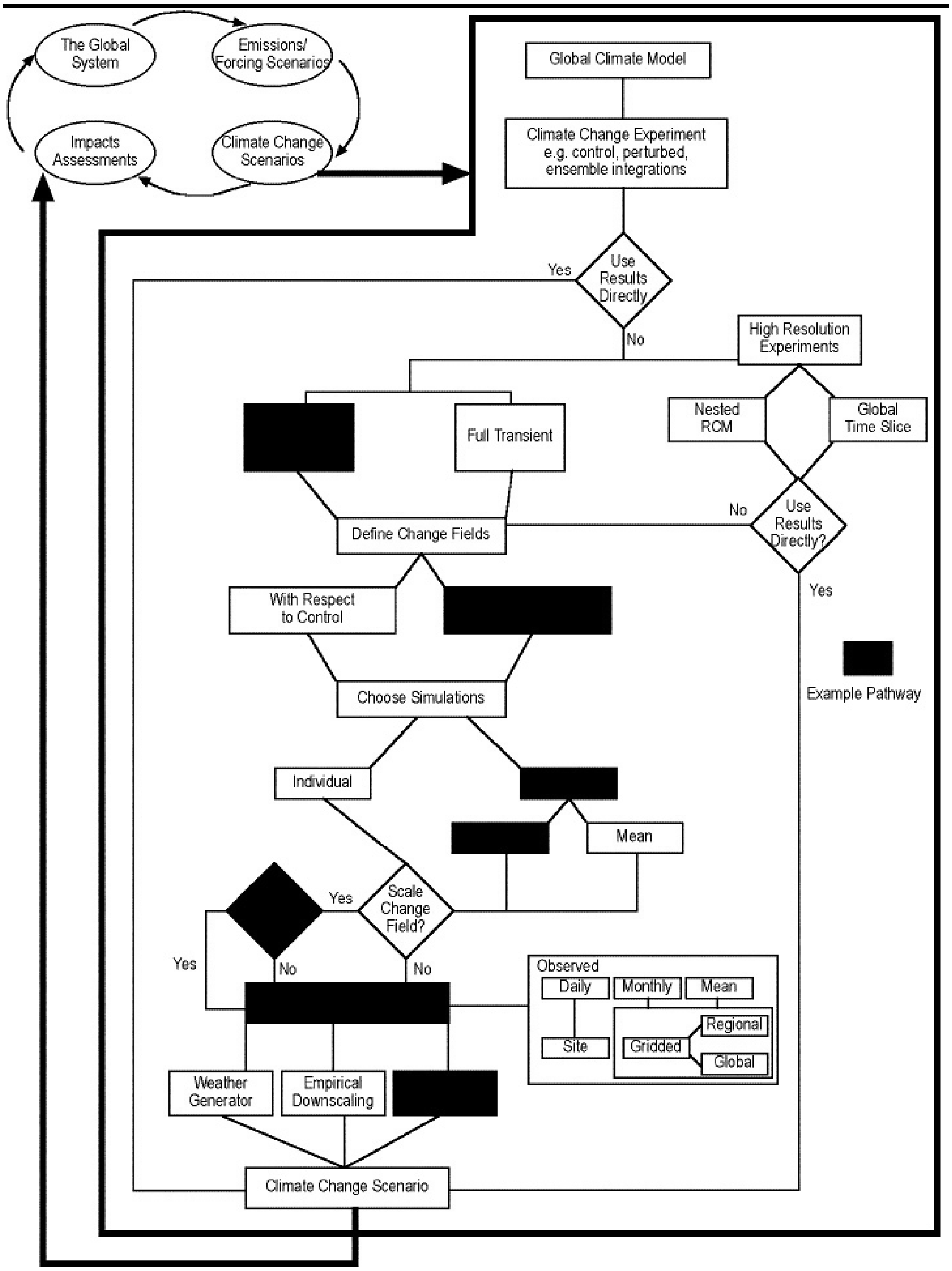
[(2)]Viner D and Hulme M. *1997 The Climate Impacts LINK Project: Applying results of the Hadley Centres climate experiments for climate change impacts assessments* Report Prepared for UK DETR , Climatic Research Unit, Norwich 16pp

[(3)]Mitchell J. F. B., Johns T. C., Gregory J. M., Tett S. F. B. 1995. *Climate response to increasing levels of greenhouse gases and sulphate aerosols.* Nature 376, 501-504.

2) Greenhouse gas only experiments (*GHG*) in which the GCM is forced with emissions of greenhouse gases similar to, but slightly higher than, IPCC scenario IS92a up to the year 2100.

3) Greenhouse gas plus sulphate aerosols (*GHG+SUL*) in which the GCM is forced with emissions of greenhouse gases similar to, but slightly higher than, IPCC scenario IS92a and with estimates of sulphate aerosol emissions also based on IS92a up to the year 2100.

Figure A.3 Framework for the Construction of Climate Change Scenarios



Source: Viner and Hulme (1997)

Four experiments have been performed with the *GHG* forcing conditions and four with the *GHG+SUL* forcing conditions. These multiple experiments (known as *ensembles*) have the same external forcing (ie increasing levels of greenhouse gases and / or sulphate aerosols) but are started with slightly different initial conditions. The purpose of undertaking ensemble simulations is to separate the change in climate due to increased greenhouse gas forcing (the greenhouse signal) from the natural climate variability generated within the GCM. Additional experiments with different emissions scenarios have now been performed. However, for the purpose of this report only the GHG and GHG+SUL with IS92a emissions[1] will be considered.

Figure A.4 Global-Average Temperature Change from 1860 - 2100

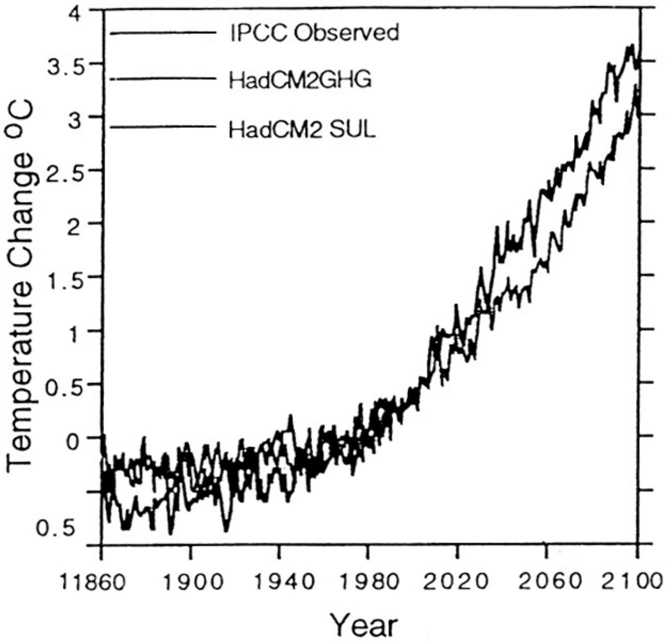


Figure A.4 shows the globally averaged annual temperature change over the period of observations (1860-1995) and the model equivalent over the same period and out to the year 2100. With increasing levels of greenhouse gases only, the temperature rise by 2100 is roughly 3.5°C and with the addition of sulphate aerosols it is reduced by about 0.5°C to 3°C. The following sections describe some of the changes in climate that may occur over the British Isles. Results from the GCM experiments are shown up to 2100 for the CON, the GHG and GHG+SUL ensembles for four GCM grid boxes designated as land overlying the British Isles.

Change in Temperature

In the GHG experiments, warming is slightly greater over Central England (3.3°C by 2100) than Northern Scotland (3°C by 2100), *see Figure A.10.* The dashed line shows the mean of the four ensemble runs which generally lie

[1] Mitchell J. F. B., Johns T. C., Gregory J. M., Tett S. F. B. 1995. *Climate response to increasing levels of greenhouse gases and sulphate aerosols.* Nature 376, 501-504.

within 1°C of each other. Seasonal changes are greatest in winter, roughly 4°C in Central England and 3.5°C over Northern Scotland by 2100 (*Figure A.12*) - whereas all summer temperatures increase by roughly 3°C and 2.2°C, respectively (*Figure A.11*). The range between the seasonal values of the ensemble members is much greater than the range in the annual values - roughly 2°C in winter and 1.5°C to 2°C in summer, compared to 1°C on annual timesteps. Annual temperatures in the SUL ensemble are roughly 0.5°C lower than the GHG ensemble by 2100 (*Figure A.10)* The SUL rises faster than GHG in the second half of the next century as the sulphate forcing lessens as a fraction related to the forcing due to greenhouse gases. The natural variability of the control run means that the SUL ensemble in these regions only rises out of the background noise by 2020 at the earliest (if at all for precipitation) whereas in the GHG ensemble this occurs by about 1960.

Change in Precipitation

The precipitation signal is much less pronounced than the temperature signal in both the GHG and GHG+SUL ensembles. There is no real change in annual precipitation over Wales and Central England by 2100 in the GHG ensemble (*Figure A.14*). Annual precipitation increases over Northern England (roughly 0.5mm / day by 2100) and Northern Scotland (roughly 0.7mm / day) with changes becoming apparent around the 1990s. The annual changes mask more pronounced seasonal changes: increases occur in winter (around 0.5mm / day) over all four grid boxes whereas very slight decreases occur in summer (around 0.25mm / day) over Wales and Central England and slight increases (0.1 mm / day) over Northern Scotland and Northern England (*Figures A.16* and *A.15* respectively). In the SUL+GHG ensemble the spatial patterns of precipitation change (on annual and seasonal timesteps) are similar to those with the GHG ensemble (increase in the north, slight decrease in the south), however, the magnitude of the change is much lower (cf *Figures A.14-A.16* with A.17-A.19).

The scatter due to variability between the ensemble runs is much greater with precipitation than with temperature, so much so that in many cases (particularly summer) the range of ensemble values still encompasses the control value even by 2100. This makes it much more difficult to disentangle the 'true' greenhouse gas induced change in precipitation from the natural variability - which may indeed be the case in the real world.

Change in other variables

Along with changes in temperature and precipitation regimes, other aspects of climate are also expected to change but there is less confidence in projections of many climate variables other than temperature. Potential evapotranspiration is likely to increase due to increases in temperature, although the nature of the changes in the other factors which affect it may offset or enhance the effects of higher temperatures. Arnell *et al.* (1) found

(1)Arnell, N., Reynard, N., King, R., Prudhommme, C. and Branson, J. 1997 *Effects of climate change on river flows and groundwater recharge; guidelines for resource assessment*. Environment Agency Technical Report No. W82.

changes in potential evapotranspiration ranging from -3 per cent to +7 per cent with SUL+GHG and GHG scenarios for the 2020s.

Figure A.5 shows the monthly frequency of weather types for one member of the SUL+GHG ensemble over the period best representing the present day (1961-1990) and two 30-year periods in the future: 2040-2069 and 2070-2099. There are some slight differences between the three periods, such as a slight increase in the number of westerlies during spring and a decrease in easterlies during spring, but on the whole the differences are rather small. From this example there is no real indication of any major changes in the circulation patterns affecting the British Isles.

Table A.2 shows some recent extreme annual and seasonal temperature anomalies from the 1961 to 1990 average and their approximate estimated return periods under current (1961-90) climate and under one of the SUL+GHG ensemble for the years centred around 2050 (from Grid Box 4, *Figure A.9*). The global warming by this date is about 1.5°C. Estimates derive from statistical analysis of the Central England Temperature record.[1]

Table A.2 ***Some Recent Extreme Annual and Seasonal Temperature Anomalies from 1961 to 1990***

	Seasonal anomaly (°C)		**Return period (years)**	
	Temperature	Anomaly	1961-90	2050
Annual 1990	10.6	+1.1	65	1.6
Summer 1976	17.8	+2.5	310	5.5
Summer 1995	17.4	+2.1	90	3
Winter 1988/9	6.5	+2.4	30	4
Winter 1962/3	-0.3	-4.4	230	∞

[1]Raper, S.C., Viner, D., Hulme, M. and Barrow, E. 1997 *Global warming and the British Isles. In Climate of the British Isles, Present, Past and Future.* Ed. by *M. Hulme and E. Barrow.* pp 326-339.

Figure A.5 ***Monthly Frequencies of the Seven Basic Lamb Weather Types and Unclassified Types (SUL1 (bold) 1961-1990, SUL1 (dashed) 2040-2069 and SUL1 (long dash) 2070-2099)***

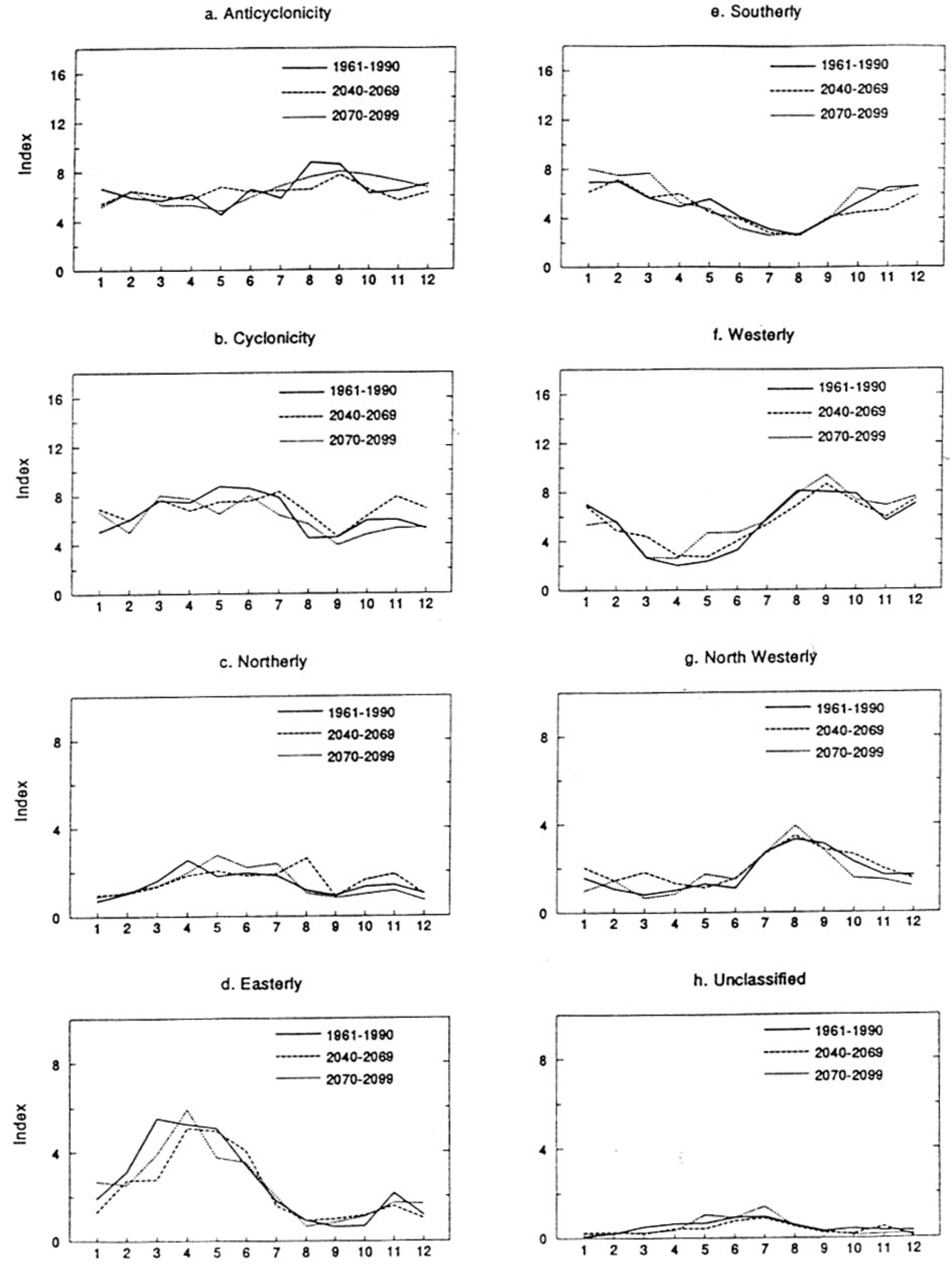


Table A.3 shows changes in daily characteristics of temperature and precipitation in four GCM grid boxes taken from one member of each of the GHG and SUL+GHG integrations for the period 2040-2069 minus the period 1961-1990.

Table A.3 Changes in Daily Characteristics of Temperature and Precipitation

	SUL+GHG 2040-2069			GHG 2040-2069		
	% change in precip.	% change in precip intensity[1]	% change in no. of days with precip.[2]	% change in precip.	% change in precip intensity[1]	% change in no. of days with precip.[2]
1. Northern Scotland						
Annual	4.1	6.5	-1.8	11.9	14.7	-1.5
Winter	3.0	10.1	-3.7	16.9	15.2	1.0
Summer	8.5	8.3	0.3	2.6	7.5	-3.1
2. Southern Scotland						
Annual	3.3	5.9	-1.1	15.2	17.6	-0.7
Winter	1.5	6.0	-2.1	21.0	17.9	1.4
Summer	2.0	4.6	-1.1	4.2	12.9	-4.4
3. Wales						
Annual	3.4	6.7	-1.1	15.2	16.0	0.3
Winter	7.6	10.9	-1.7	26.1	17.4	3.8
Summer	-4.0	3.6	-3.6	2.9	14.6	-4.4
4. Central England						
Annual	2.4	8.4	-2.2	13.0	16.0	-0.6
Winter	6.7	9.4	-1.4	24.1	20.8	1.5
Summer	-0.7	5.7	-2.5	-2.1	11.8	-5.2

[1]Percentage change in mean precipitation on wet days
[2]Percentage change in number of days with >0.1mm precipitation

Rates of Change

The rate of future climate change is very important. The IPCC scenarios suggests rates of global-mean temperature change up to 0.2°C per decade which appear unprecedented in the historical record. Parry *et al* [1]. identify three types of critical levels of climate change:

1) critical changes of climatic averages;

2) critical changes of climatic variability;

3) critical rates of climatic change.

Obviously, these critical levels will be heavily case-dependent and Parry *et al.* suggest a stepwise method for defining critical climate change based on region and sector. The rate of future change may not necessarily be constant, and there is a possibility of fairly rapid and perhaps unexpected changes occurring. For instance, Klein Tank and Können[2] assessed the impact of a sudden weakening in the Gulf Stream / North Atlantic Drift on temperatures

[1]Parry, M.L., Carter, T.R. and Hulme, M. 1997 *What is a dangerous climate change?* Glob. Env. Change 6, 1-6.

[2]Klein Tank, A.M.G. and Konnen, G.P. *1997 Simple temperature scenario for a gulf stream induced climate change.* Climatic Change 37, 505-512.

in the Netherlands. Although it is beyond the capability of current GCMs to fully simulate such detailed features, many do suggest a weakening of the thermohaline circulation in the oceans with enhanced greenhouse gas warming. Therefore, a pronounced change in the North Atlantic circulation in the future should not be discounted. In the study, days with advection of airmasses of maritime origin had their observed temperatures lowered by a fixed value to represent the influence of a cooler Atlantic Ocean. Temperatures were left unchanged on days with non-maritime airmasses. Such changes lead to a decrease in mean temperature throughout the year and an increase in the relative frequency of cold winters and cool summers.
A similar result might be anticipated for the British Isles.

A1.3 UNCERTAINTIES IN SCENARIOS OF FUTURE CLIMATE CHANGE

A1.3.1 Emissions Scenarios

There is great uncertainty associated with forecasts of future emissions of greenhouse gases and further uncertainty involved in converting emissions to actual atmospheric concentrations. Future emissions controls, such as those included in quantified emission limitation and reduction commitments under the Kyoto Protocol, will also affect the rates of change (the recent agreement is estimated to produce a reduction in global mean temperature rise of 0.27°C by 2100 from the IS92a IPCC emissions scenario, given no change in sulphate aerosols.). It should be noted that the adopted sulphate emission scenario used for the GHG+SUL presented here over-estimates present-day emissions and, probably, future emissions. This overestimate, combined with the very simplistic treatment of aerosol chemistry and its radiative forcing effects suggests the scenario will soon be superseded by an improved greenhouse gas plus sulphate aerosol scenario (Mitchell, in press; Hulme, pers. comm.).

A1.3.2 Climate modelling

Many aspects of the climate system remain imperfectly understood and GCMs are being constantly updated. To a certain extent, the rates of future change are dependent on the characteristics of the Hadley Centre model (HADCM2). Future model improvements or different GCMs may well affect the rate and spatial patterns of future climate change presented here. For instance the results presented here do not take into account the uncertainty in the range of values for the climate sensitivity to a given increase in radiative forcing. This varies between GCMs and is usually taken to range from 1.5°C to 4.5°C (in the HADCM2 GCM it is roughly 2.5°C).

A1.3.3 Spatial and temporal scales

It is likely that changes in the frequency of extremes will have a greater impact upon the environment and human activities than changes in mean climate. Unfortunately, however, at the present time GCMs cannot produce reliable estimates of localised extreme weather events such as storms. Indeed there is much greater uncertainty with GCM scenarios at the spatial and temporal scales required for impact assessment. Techniques such as 'downscaling' may be used to improve the resolution of GCM scenarios but they will always be constrained by the quality of the input data from the GCM.

A1.3.4 Disentangling the anthropogenic climate change or trend from natural variability

From the review of recent climate variability in the British Isles in Section 1.2 it is clear that significant levels of variability lie within the bounds of what is considered to be our stable climate. Anthropogenically-induced climate change will be superimposed upon this natural variability or noise. How it manifests itself is an issue for detection and modelling studies to determine. What is clear from the scenarios presented here is that for variables such as precipitation it may be some time (2220 or later) before this is possible. In the GHG+SUL ensemble, for example, the forcing gradually increases temperatures but each future decade need not be warmer than the previous, as for a decade or two the natural variability of the model could act to counter the anthropogenic influence. Indeed, for an area as small as the British Isles it may still be possible for an extremely cool year to occur in the 2040s which would be no different in mean value from an average year occurring today. Taking into account the natural internal GCM variability through the use of ensemble experiments makes this even harder - although the practise will aid in distinguishing the 'natural' variability from the anthropogenic signal on a regional scale.

Given these uncertainties, it is important to note that regional changes in climate derived from GCM experiments are scenarios and should not be considered predictions.

A1.4 CONTRACTION AND CONVERGENCE

The Global Commons Institute (GCI) has developed the idea of contraction and convergence which combines emission reduction with the concept of equity in allowed emission rates between developed and developing countries.

The model the GCI has developed works with the relationship between emissions and concentrations developed by the IPCC (*Table A.4*).

Table A.4 Total Emissions of CO_2 and Atmospheric CO_2 Concentrations

Accumulated CO_2 equivalent emissions 1990-2100 (GT Carbon)	**Atmospheric concentrations of CO_2 in parts per million by volume (ppmv)**
300 - 430	350
630 - 650	450
870 - 890	550
1030 - 1190	650
1200 - 1300	750

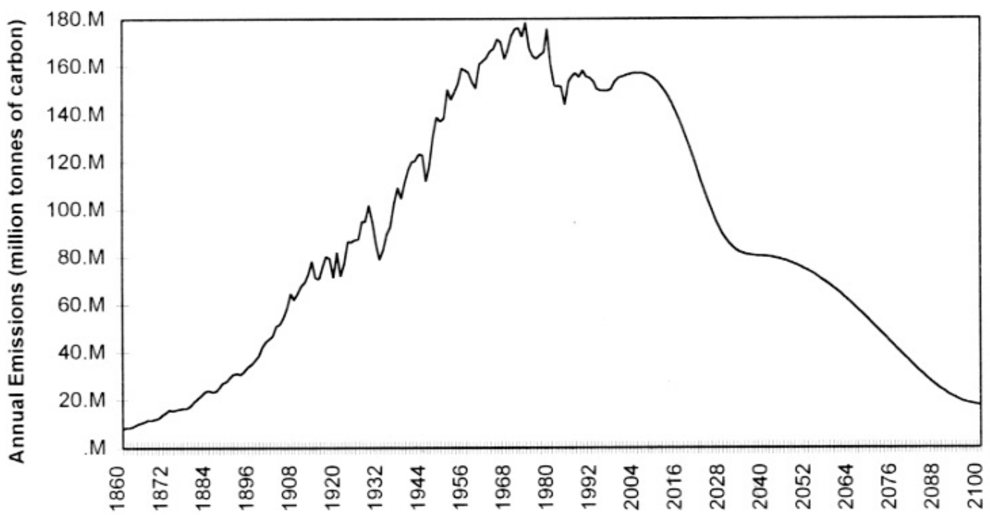
Source: IPCC (1994) Radiative Forcing of Climate Change. The 1994 Report of the Scientific Assessment Working Group of IPCC.

The IPCC's IS92a scenario, generally regarded as a "business as usual" scenario, will result in 1500 GTC emissions and an atmospheric concentration of CO_2 in excess of 750 ppmv. These compare with a pre-industrial concentration of 280 ppmv and current concentration of 360 ppmv. Stabilisation of emissions at current emission rates will not stabilise concentrations by 2100; they will reach about 500 ppmv by 2100 and will slowly rise for several hundred years (1) .

The GCI has developed a model that allows emission pathways to be simulated in a way that will result in alternative atmospheric concentrations. In order to achieve the required cumulated emission rates and a future time at which emission rates will be stabilised, GCI has assumed that, over time, total emissions are reduced and that emission rates on a per capita basis are harmonised between developed and developing countries.

The emissions pathway for the UK consistent with the 550 ppmv model run is shown in *Figure A.6.*

Figure A.6 Historical and Allocated CO_2 Emissions for the UK (1860-2100)



(1) IPCC (1994) Radiative Forcing of Climate Change. The 1994 Report of the Scientific Assessment Working Group of IPCC.

A1.5 SAFE EMISSION CORRIDORS

Dutch researchers developed the concept of safe emission corridors[(1)]. These corridors specify the range of global emissions from 1990 to a target year that comply with long term climate goals. They have used this analysis to link long term goals with near term emission targets. *Alcamo et al* [(2)] determine Safe Emission Corridors given the following constraints:

- the cumulative increase in global average surface temperatures 1990 - 2100 should be no more than 1.5°C above present levels (no more than 2ºC above pre-industrial levels);
- the global rate of temperature increase 1990 - 2100 should not exceed 0.15°C / decade, except for the first two decades;
- sea-levels should not rise by more than 30cm up to 2100 relative to 1990;
- the maximum rate of global emission reduction is 2% per year.

These constraints are considered by *Alcamo et al.* as intermediate and compatible with the FCCC's objectives "to allow ecosystems to adapt naturally to climate change" and "to ensure that food production is not threatened" while allowing "economic development to proceed in a sustainable manner."

Using the constraints above, Alcamo's IMAGE2 climate model results in a global emission corridor in the year 2010 of 7.6 - 12.4 Gt C per year of anthropogenic CO_2, CH_4 and N_2O emissions. Since global emissions in 1990 are estimated to be 9.8 Gt C/year, this range represents 78 - 127% of emissions in 1990.

They used this in order to estimate what would be the required reductions in emissions in the period 2010 to 2030 from Annex I and non-Annex I parties for two options on emission reductions to 2010: stabilisation of emissions at 1990 levels (a US proposal) and a 15% reduction (EU proposal). The resultant requirements for emission reductions in the later period are shown in *Figure A.7*.

(1) Alcamo J, Onigkeit J and Berk M (1997) Emission Corridors and Emission Trends: Comparing Protocol Proposals of AOSIS, EU, Japan and USA. Seminar, Bonn 30 October 1997.

(2) Alcamo J., Krol M., Posch M. 1995. *An integrated analysis of sulphur emissions, acid deposition and climate change.* Water, Air and Soil Pollution 85, 1539-1550.

Figure A.7 Emission reduction to achieve middle of corridor 2010-2030 for two 1990-2010 reduction options

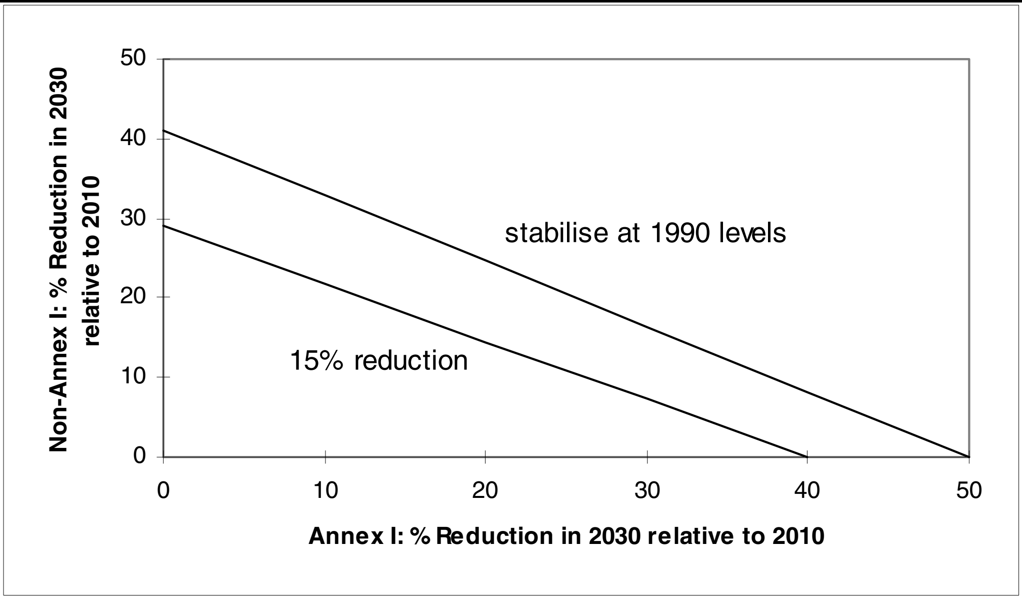
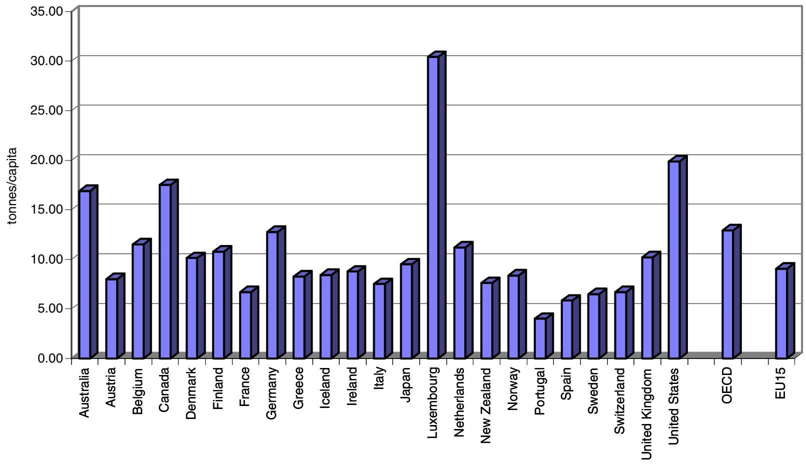


Figure A.8 *Per Capita CO_2 Emissions (1990)*



Emissions of the main gases are compared to those from other developed countries on a per capita basis in *Figures A.8.* The UK is above the EU average for CO_2 emissions but less than the OECD average which is dominated by the high emission rates in the US. The highest per capita emissions are in Luxembourg where steel industry emissions are very high

A1.6 *PROJECTIONS*

A1.6.1 *EU Projections*

EU projections have been developed for energy related CO_2 emissions (Table *A.5*). The largest growth area is the transport sector whereas there are expected to be significant reductions in industrial emissions associated particularly with changes in the structure of the industrial sector. Power production is also increasing significantly.

A1.6.2 *Global Projections*

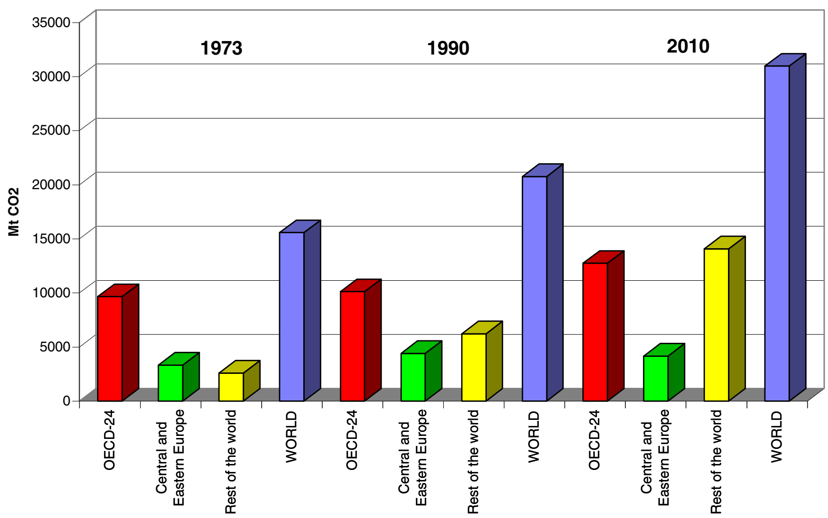
Figure *A.9* includes projections of CO_2 emissions for different regions. These are emission rates in the absence of policy measures and hence OECD emission rates are projected to increase. In response to the Kyoto Protocol the rate of emissions growth will be less than this. This depends, to some extent, on decisions relating to the flexibility mechanisms including rules for emissions trading, the way in which the growth in OECD emissions can be offset through reductions in emissions from Central and Eastern Europe or the developing world, plus the role of absorption by sinks.

Table A.5 *EU Emission Projections*

	Million tonnes	% Change over 1990			
	1990	2000	2005	2010	2020
Industry	626	-14%	-14%	-15%	-15%
Transport	743	+22%	+31%	+39%	+49%
Domestic/ tertiary	654	-1%	+2%	+4%	+6%
Power/heat production	1036	-2%	+2%	+2%	+17%
energy branch	141	+9%	+11%	+12%	+13%
Total	3200	+2%	+6%	+8%	+16%

Source: Second Communication from the European Commission under the UN Framework Convention on Climate Change. 26 June 1998

Figure A.9 *World Energy-related CO_2 Emissions*



International Energy Agency (1996)

The UK will be impacted most significantly by emissions trends in non-Annex 1 parties, which are rapidly becoming the major source of global emissions. However, at this stage the UNFCCC has not introduced quantified emission limitation and reduction commitments for these countries. This is partly because of their level of economic development and the likely costs of policy measures to reduce emissions, and partly in recognition of their low historical contributions to emissions. CO_2 molecules remain in the atmosphere for significant periods of time affecting climate for years to come, *see Table A.6.*

Table A.6 Historic CO_2 and CH_4 Emission Rates

Region	Industrial CO_2	Total CO_2	$CO_2 + CH_4$
OECD North America	33.2	29.7	29.2
OECD Europe	26.1	16.6	16.4
Eastern Europe	5.5	4.8	4.7
Former USSR	14.1	12.5	12.4
Japan	3.7	2.3	2.3
Oceana	1.1	1.9	1.9
China	5.5	6.0	6.3
India	1.6	4.5	4.8
Other Asia	1.5	5.0	5.2
N Africa & Mid-East	2.2	1.7	1.8
Other Africa	1.6	5.2	5.2
Brazil	0.7	3.3	3.3
Other Latin America	3.2	6.5	6.5
Developed Countries	83.8	67.8	66.9
Developing Countries	16.2	32.2	33.1

Source: Grubler and Nakicenovic (1991) in: Banuri T *et al* (1996) Equity and Social Considerations in: Bruce JP, Lee H and Haites EF (Eds) Climate Change 1995. Economic and Social Dimensions of Climate Change. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

A1.7 UK FACILITIES FOR CLIMATE CHANGE DATA

There are two main projects in the UK which facilitate researchers and others in gaining access to climate change scenarios for use in impacts research.

A1.7.1 The Hadley Centre Climate Impacts LINK Project

The Climate Impacts LINK Project (http://www.cru.uea.ac.uk/link) commenced in 1991. It is funded by the DETR and is based at the Climatic Research Unit, University of East Anglia. The overall aims of the project are:

- liaison with the climate impacts community in order to determine the nature of their climate change data requirements and provision of information to the impacts community to help them become familiar with the appropriate use and interpretation of GCM results;
- liaison with the Hadley Centre so that archived results of the GCM climate change experiments can be tailored to the needs of the impacts community;
- development and provision of climate change scenarios for the impacts community.

A1.7.2 *The IPCC Data Distribution Centre*

The Data Distribution Centre (DDC) of the IPCC (http://ipcc-ddc.cru.uea.ac) has been established to facilitate the timely distribution of a consistent set of up-to-date scenarios of changes in climate and related environmental and socio-economic factors for use in climate impacts assessments. The intention is that these new assessments can feed into the review process of the IPCC, in particular to the Third Assessment Report (TAR). The initiative to establish a DDC grew out of a recommendation by the IPCC Task Group on Climate Scenarios for Impacts Assessments (TGCIA). This Task Group was itself formed following a recommendation made at the IPCC Workshop on Regional Climate Change Projections for Impact Assessment (London, 24-26 September 1996). The establishment of the DDC was approved by the IPCC Bureau at its Thirteenth Session (9-11 July 1997) and it was subsequently determined at the XIIIth IPCC Plenary (Maldives, 22-28 September 1997) that the DDC would be a shared operation between the CRU in the United Kingdom and the Deutsches Klimarechenzentrum (DKRZ) in Germany.

Figure A.10 ***10 Year Moving Average of Mean Annual Temperature Change (C) in the Four HADCM 2 GCM Land Grid Boxes Overlying the British Isles. Results are shown for the CON, GHG1-4 and GHG 1-4 ensemble mean experiments.***

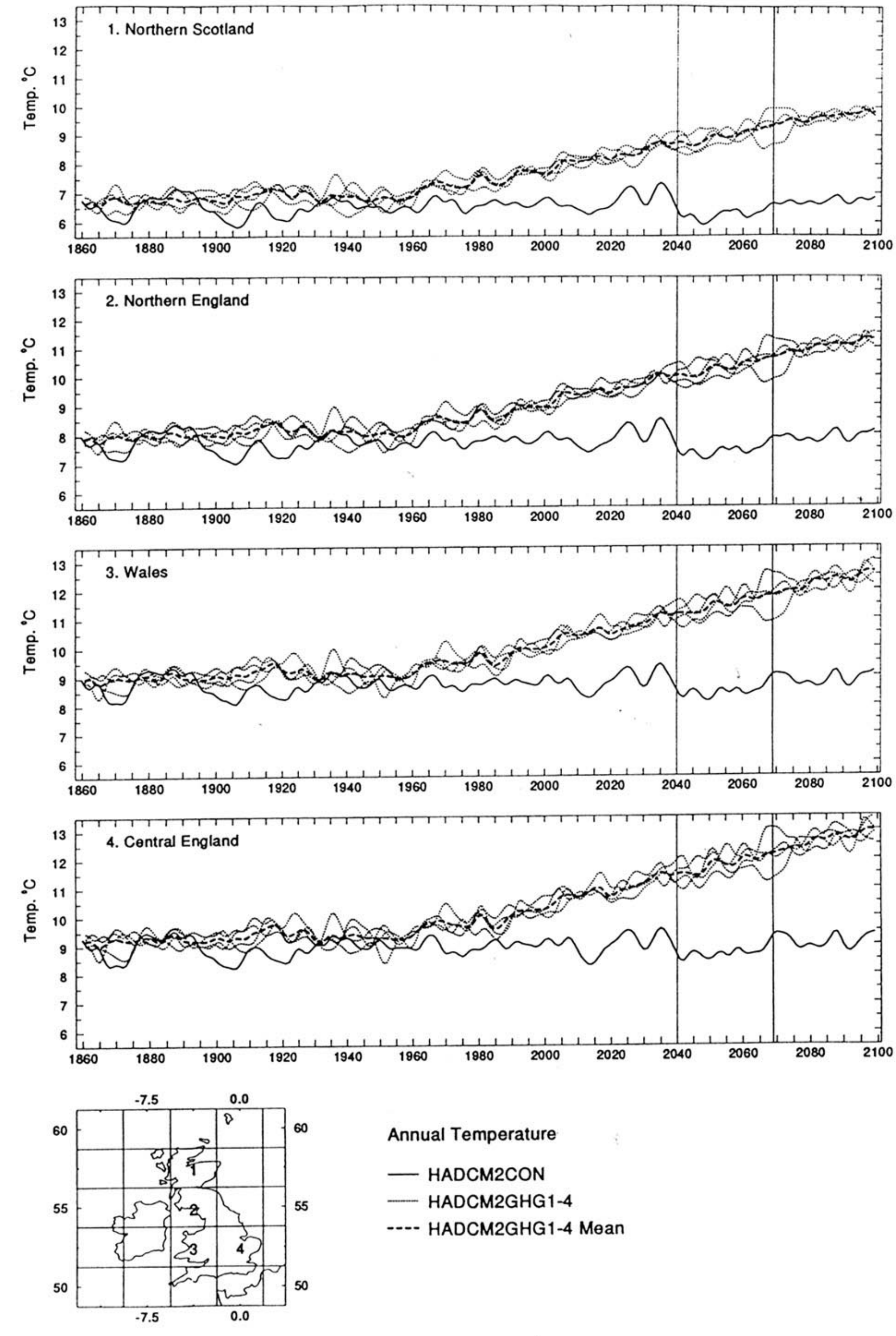


Figure A.11 10 Year Moving Average of Mean Summer (JJA) Temperature Change (C) in the Four HADCM 2 GCM Land Grid Boxes Overlying the British Isles. Results are shown for the CON, GHG1-4 and GHG 1-4 ensemble mean experiments.

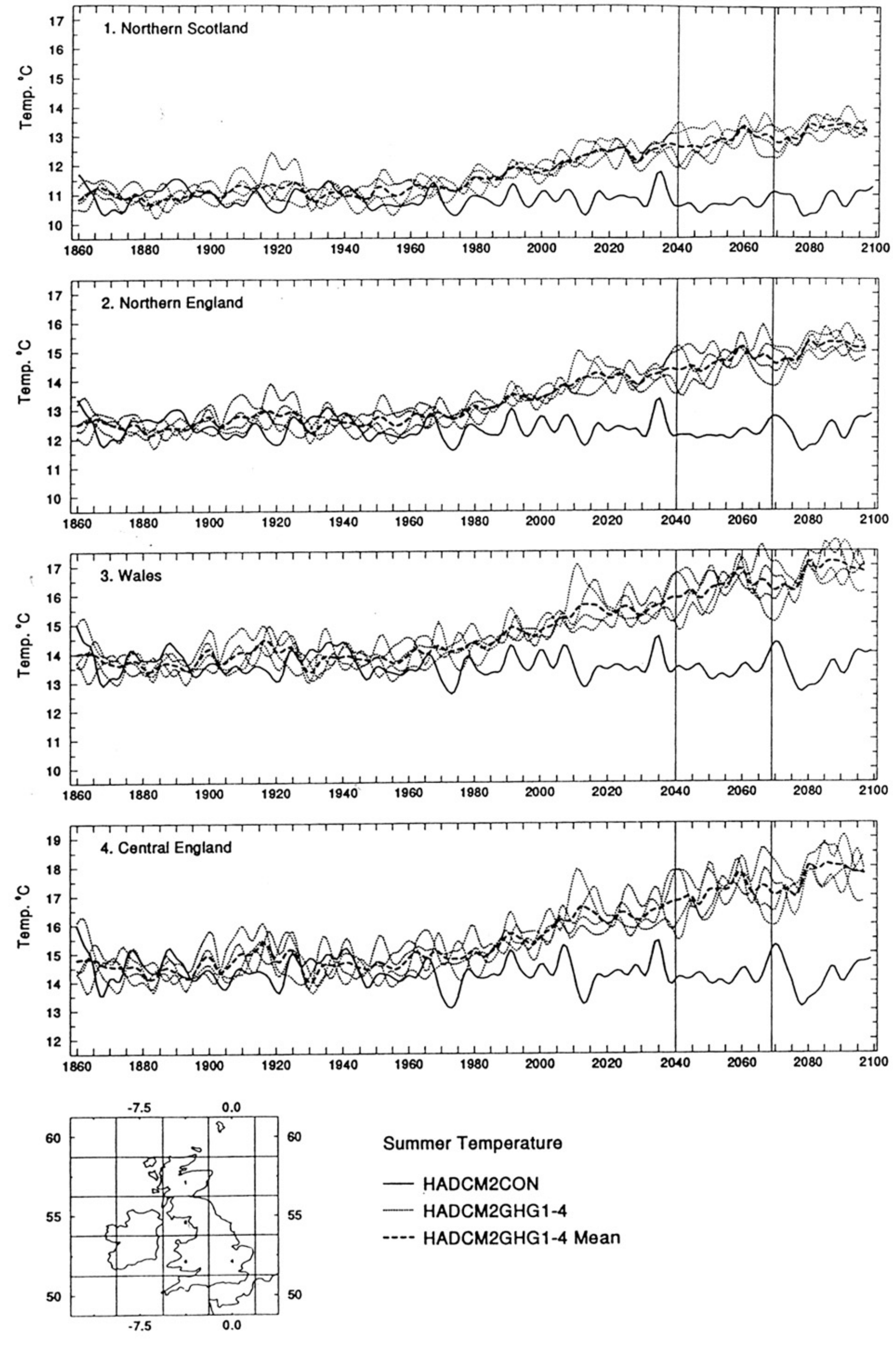


Figure A.12 10 Year Moving Average of Mean Winter (DJF) Temperature Change (C) in the Four HADCM 2 GCM Land Grid Boxes Overlying the British Isles. Results are shown for the CON, GHG1-4 and GHG 1-4 ensemble mean experiments.

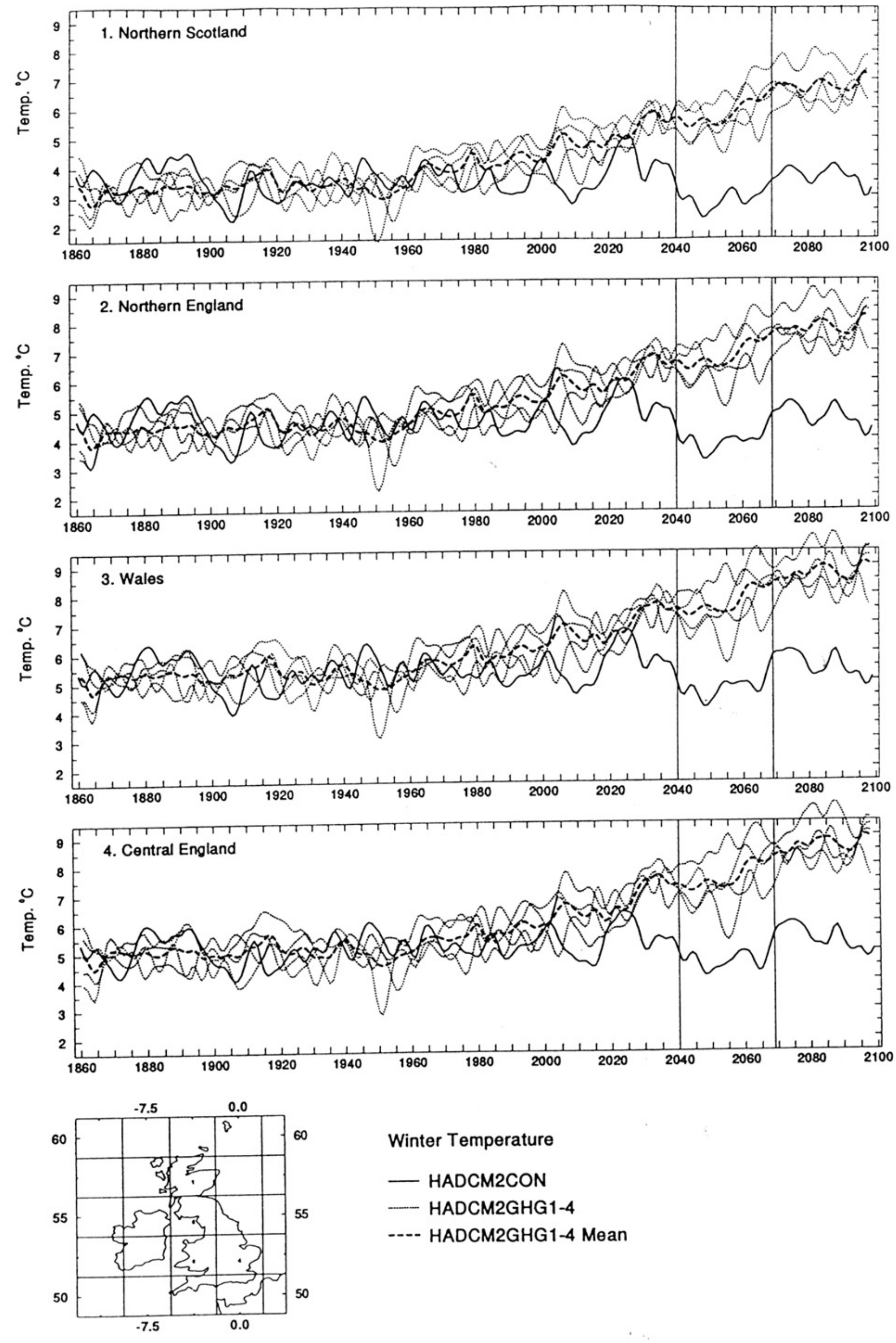


Figure A.13 10 Year Moving Average of Mean Annual (DJF) Temperature Change (C) in the Four HADCM 2 GCM Land Grid Boxes Overlying the British Isles. Results are shown for the CON, SUL1-3 and SUL1-3 ensemble mean experiments.

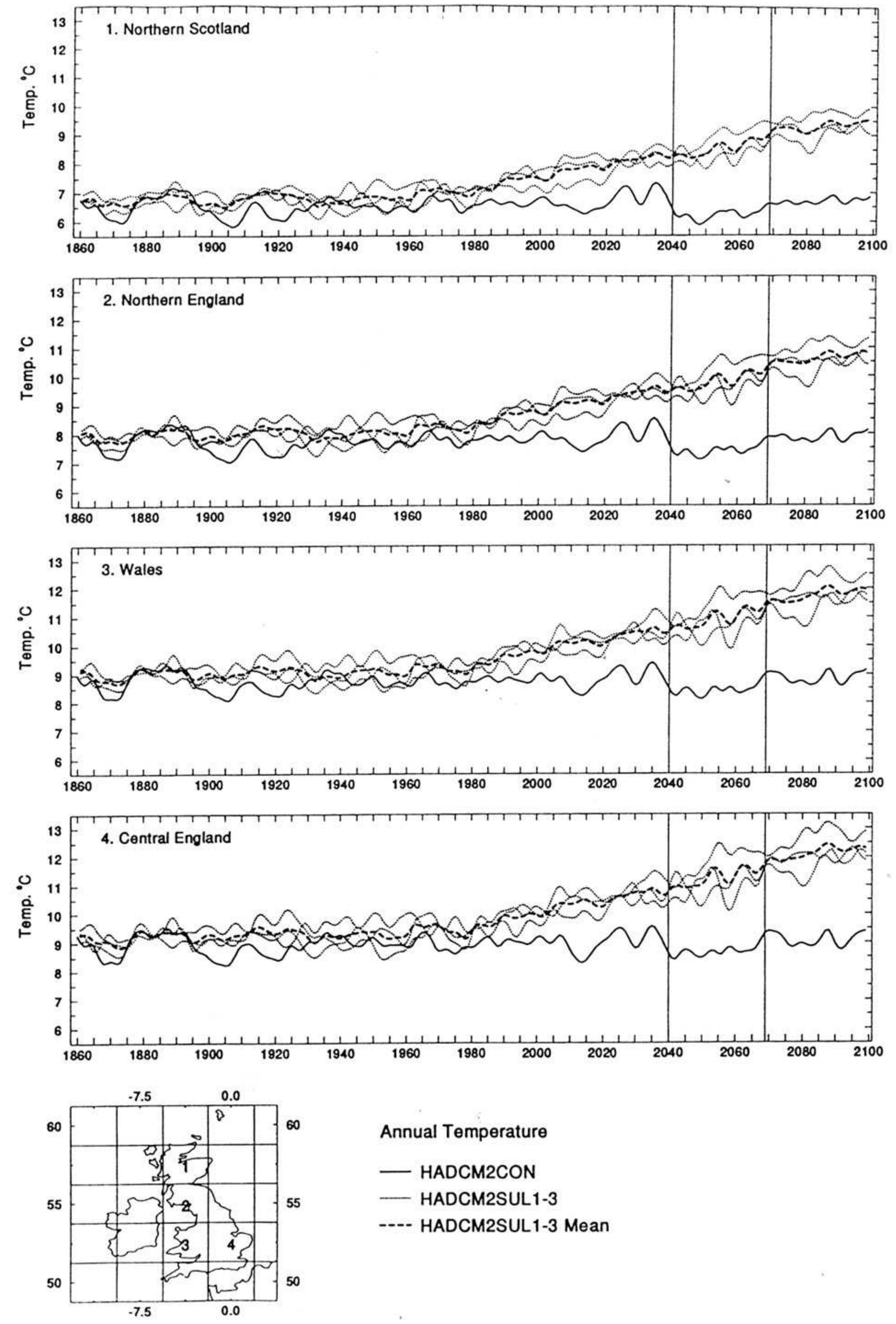


Figure A.14 10 Year Moving Average of Mean Annual Precipitation Change (mm/day) in the Four HADCM 2 GCM Land Grid Boxes Overlying the British Isles. Results are shown for the CON, GHG1-4 and GHG1-4 ensemble mean experiments.

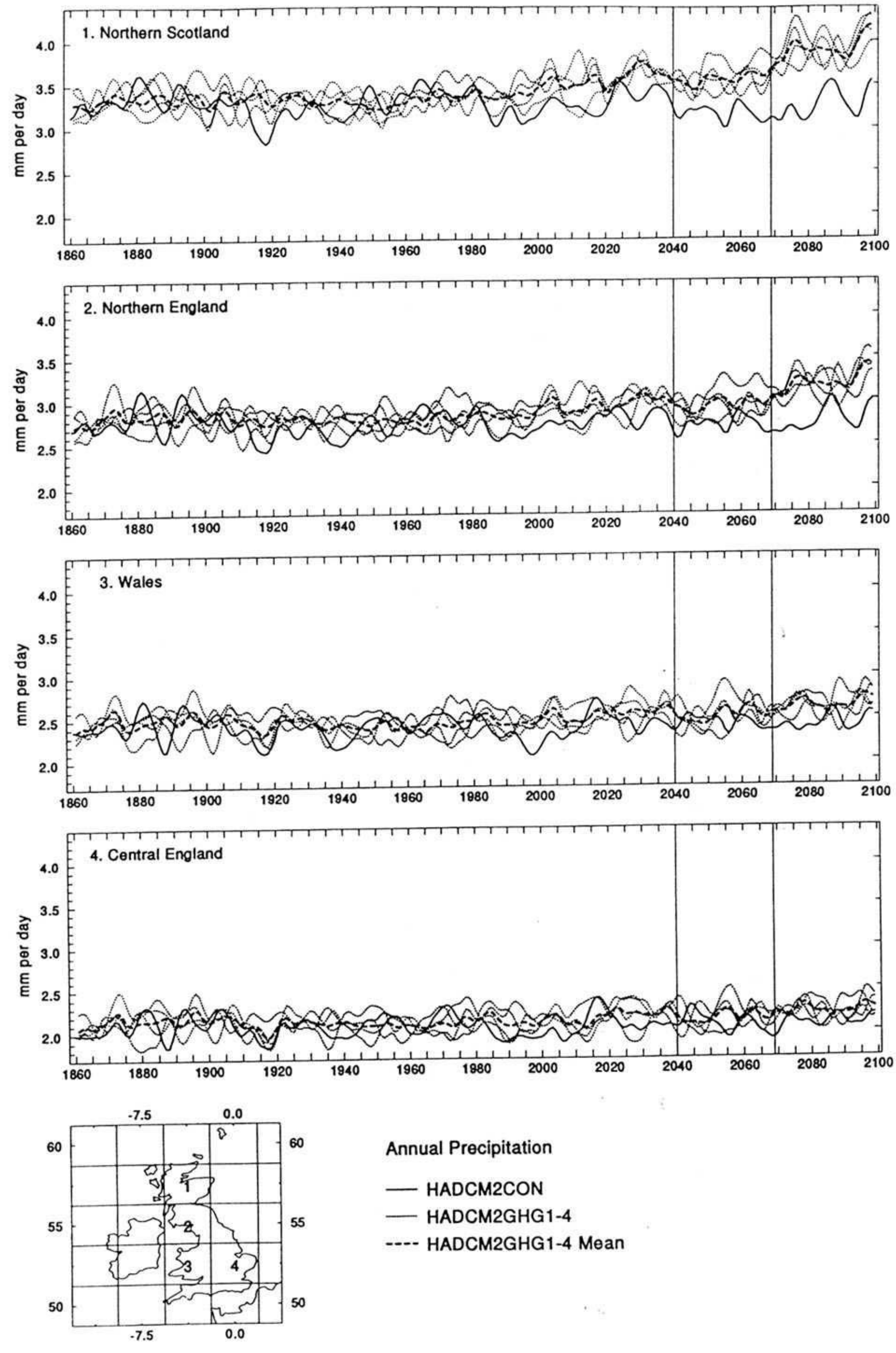


Figure A.15 10 Year Moving Average of Mean Summer (JJA) Precipitation Change (mm/day) in the Four HADCM 2 GCM Land Grid Boxes Overlying the British Isles. Results are shown for the CON, GHG1-4 and GHG1-4 ensemble mean experiments.

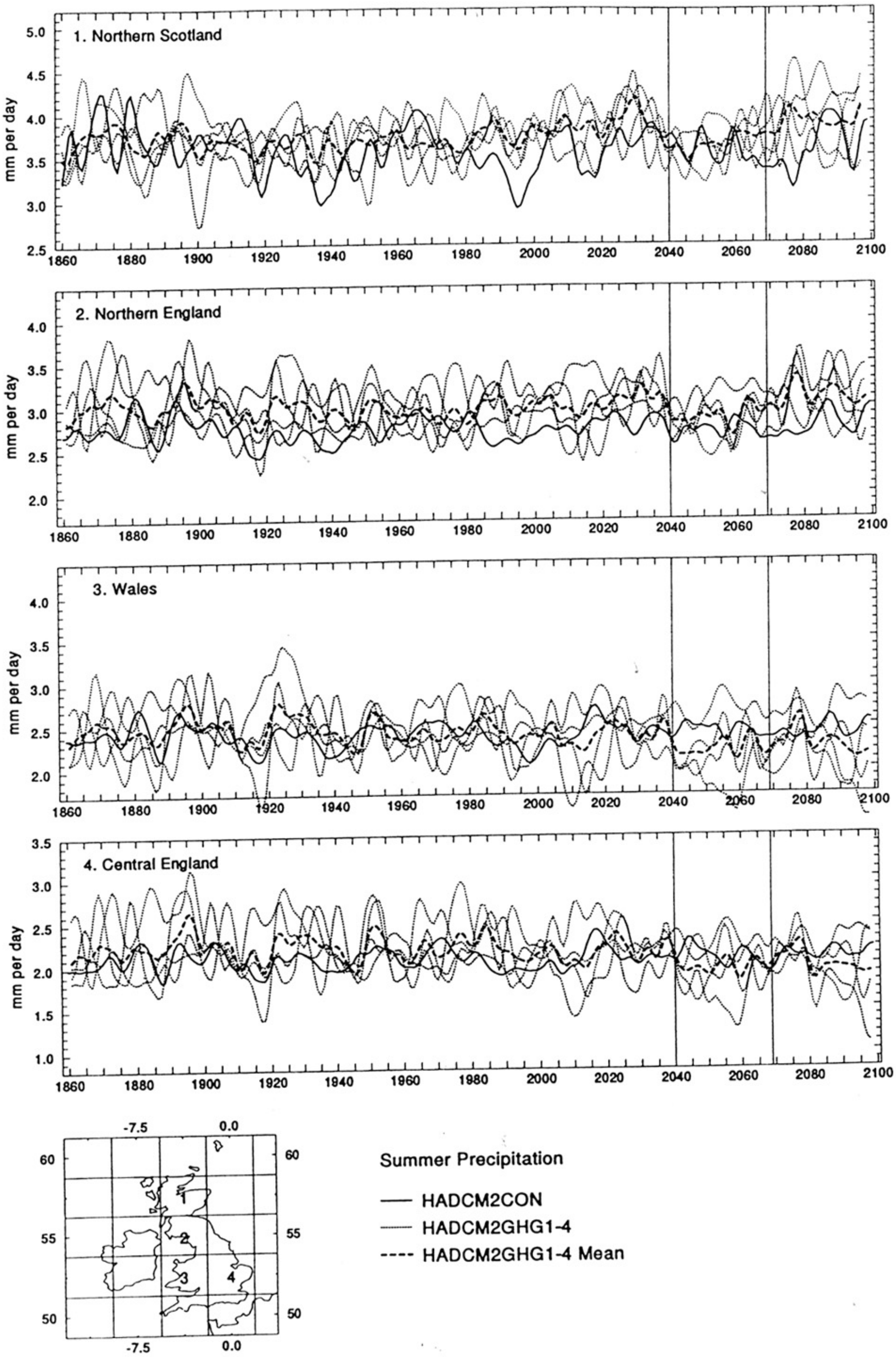


Figure A.16 10 Year Moving Average of Mean Winter (DJF) Precipitation Change (mm/day) in the Four HADCM 2 GCM Land Grid Boxes Overlying the British Isles. Results are shown for the CON, GHG1-4 and GHG1-4 ensemble mean experiments.

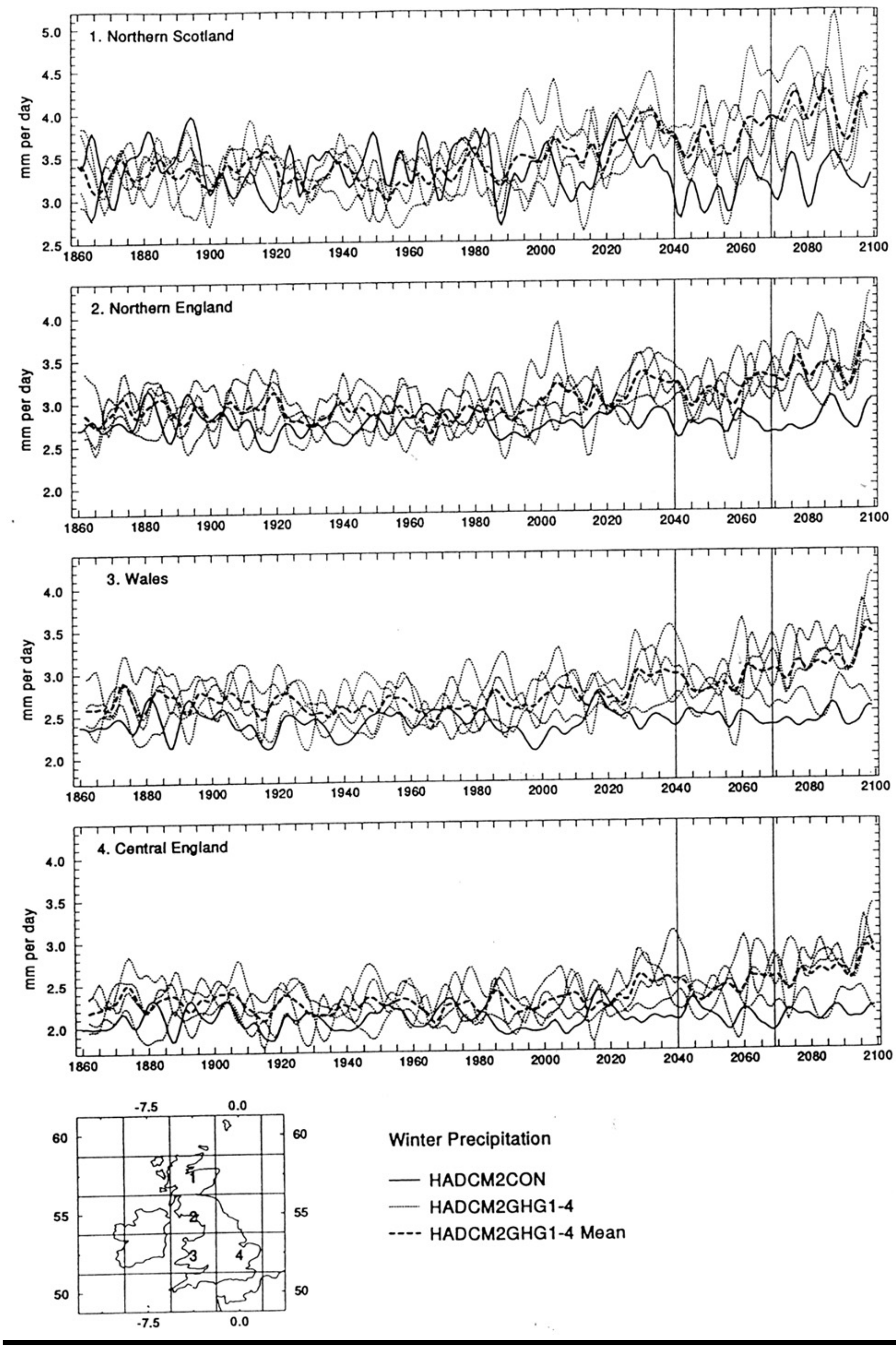


Figure A.17 ***10 Year Moving Average of Mean Annual Precipitation Change (mm/day) in the Four HADCM 2 GCM Land Grid Boxes Overlying the British Isles. Results are shown for the CON, SUL1-3 and SUL1-3 ensemble mean experiments.***

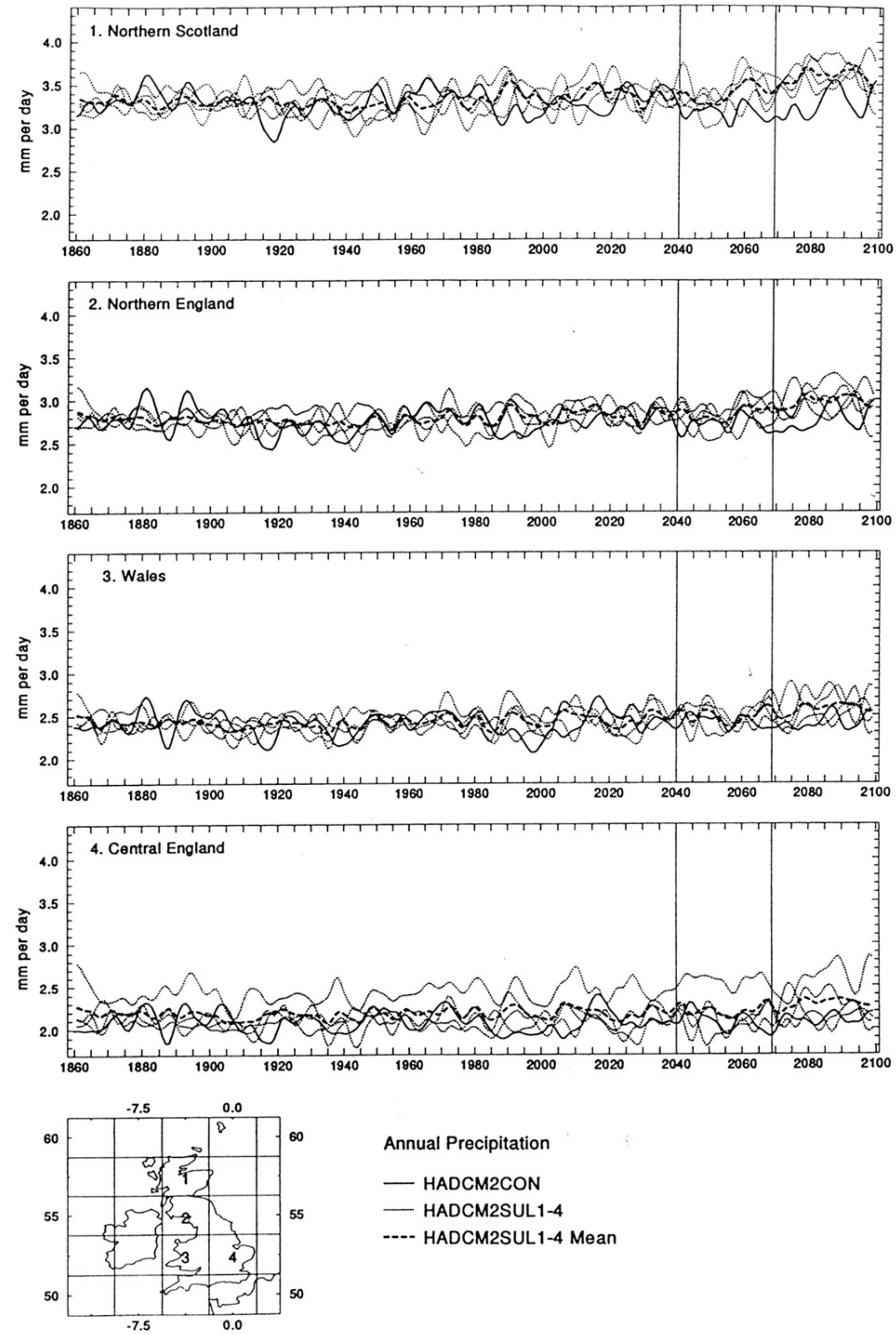


Figure A.18 10 Year Moving Average of Mean Summer (JJA) Precipitation Change (mm/day) in the Four HADCM 2 GCM Land Grid Boxes Overlying the British Isles. Results are shown for the CON, SUL1-4 and SUL1-4 ensemble mean experiments.

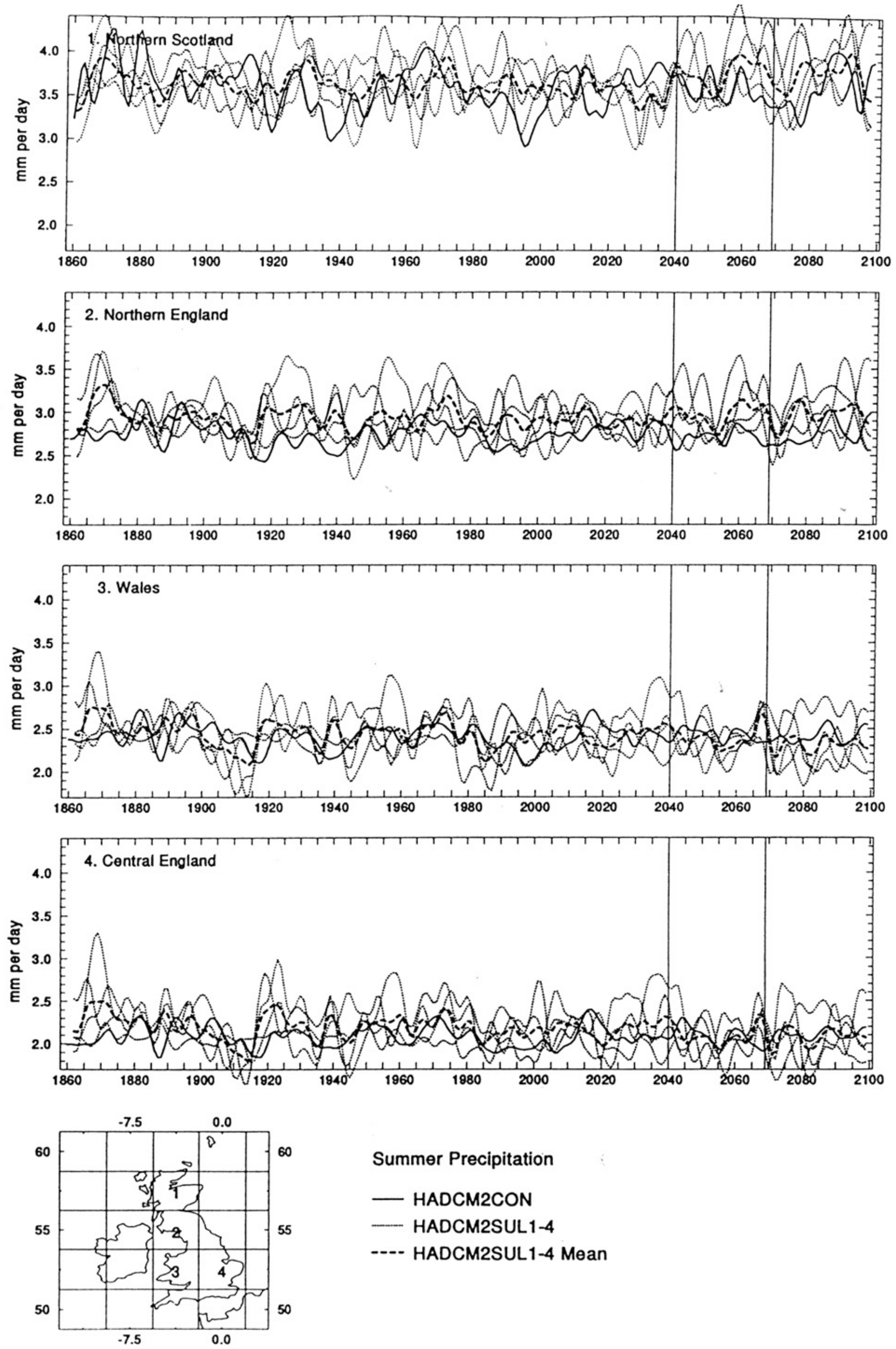
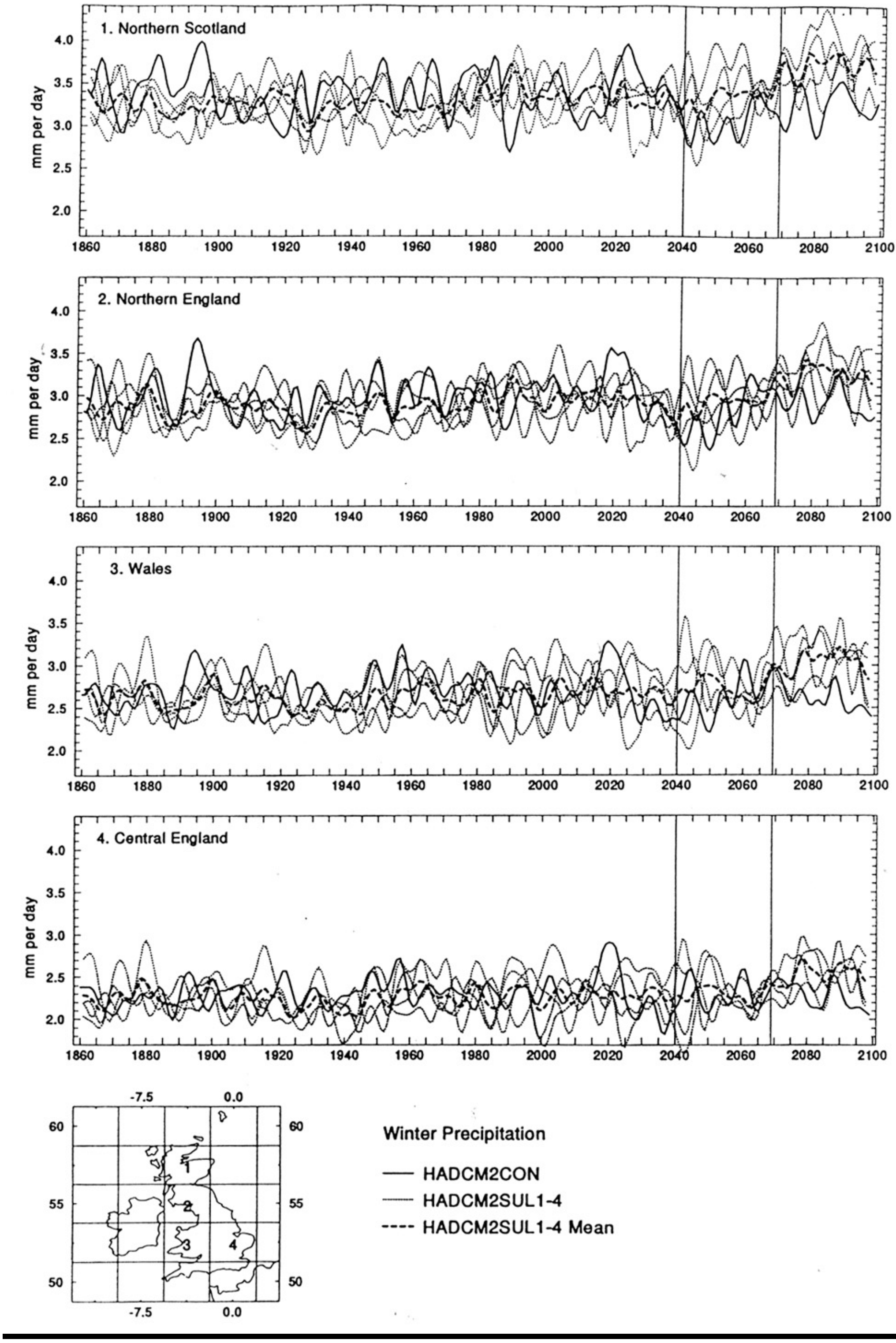


Figure A.19 10 Year Moving Average of Mean Winter (DJF) Precipitation Change (mm/day) in the Four HADCM 2 GCM Land Grid Boxes Overlying the British Isles. Results are shown for the CON, SUL1-4 and SUL1-4 ensemble mean experiments.



Annex B

Hydrology and Air Pollution

B1 IMPACTS OF CLIMATE CHANGE ON HYDROLOGY AND AIR POLLUTION

B1.1 HYDROLOGY

Table B1 Summary of Some Hydrological Impact Studies Undertaken in England and Wales

Author / Study	**Study Area**	**Type of hydrologic model**	**Climate Scenario**	**Impacts on river flows**
CCIRG (1996)	Whole UK	MORECS	CCIRG 1996 (UKTR 2050s)	Annual runoff 15-25% increase parts of Scotland, 5-15% Northern England, 5-15% decrease over Southwest and East Anglia, 15-25% south east England.
	6 representative catchments in England and Wales	Daily time-step hydrological model	CCIRG 1996 (UKTR 2050s)	Summer flows reduced, winter flows possibly reduced in southern Britain. Winter flows increase and summer flows little change on north and west Britain.
Arnell and Reynard (1996)	21 catchments in Great Britain	Daily precipitation-runoff model	CCIRG 1991 + three potential evapotrans-piration scenarios	Wide range in impacts due to: differences between climate scenarios and catchment characteristics. Annual runoff change ranged from +20% to -20%. General increase in proportion of winter runoff. Changes small relative to year-to-year variability. Snowmelt almost entirely eliminated.
Boorman and Sefton (1997)	3 UK catchments	Two daily precipitation runoff models; IHACRES, PDSM	UKHI and CCC (Hulme *et al*., 1994)	Concerned with uncertainty related to methodology: results sensitive to differences in climate scenarios, hydrological models, catchment characteristics and the flow indices examined.
Sefton and Boorman (1997)	39 UK catchments	IHACRES	UKHI and CCC (Hulme *et al*., 1994)	Given the uncertainties noted above, results show severe reductions in low flows in central and eastern England whilst flooding increases in the north and west.
Kilsby *et al*. (1997)	Tyne river basin	NUARNO conceptual, hourly lumped catchment model	Downscaled scenarios from HADCM2 SUL (Daily and hourly)	Higher evaporation produces increase frequency of low flows offset by an increase in precipitation. No overall change in mean flow, change in seasonal distribution.
Wilby *et al*. (1994)	Eight catchments, sensitivity test on the Coln (Cotswolds)	Semi-distributed daily time step catchment model	Sensitivity study - change in the frequency of certain weather conditions	Increasing the ratio of anticyclonic to cyclonic weather types causes a decrease in flow volumes.

B1.1.1 Recent results from the Hadley Centre for Climate Prediction

Sixty catchments were selected for use with a conceptual daily water balance model. The models were run over a baseline period (1961-1990) and then forced with a set of monthly changes in potential evaporation and precipitation from twelve climate change scenarios representing the 2020s. Details of the scenarios and the annual changes in temperature, precipitation and potential evapotranspiration averaged over four regions of the British Isles are given in *Table B.2*. The results were expressed as per cent change in monthly and annual runoff and the catchments were aggregated into five regions for the UK based loosely on GCM grid box boundaries, and into catchments with and without major groundwater contributions. The results are presented for catchments without (*Table B.3*) and with (*Table B.4*) significant groundwater contributions.

Table B2 Details of Some of the Climate Change Scenarios and Their Results Averaged for the UK Used in Arnell et al (1997)

Scenario	**Rescaled or time-slice?**	**Comments**	**Change in global T by the 2020s**	**Change in UK T by the 2020s**	**Change in UK Annual Precip.**	**Change in UK Annual potential evapotranspiration**
HADCM1	Rescaled (2070s)	From UKTR, as used by CCIRG 1996	1.0°C	0.9°C	3.5%	4.5%
GG1m	Rescaled (2070-2099)	HADCM2 GHG. One member of the ensemble. Rescaled*, with medium climate sensitivity (2.5°C)	1.0°C	0.9°C	3.8%	-0.5%
GS1t	Time slice (2010-2039)	HADCM2 GHG+SUL. One member of the ensemble.	1.2°C	0.6°C	2.0%	0.3%
GS1m	Rescaled (2070-2099)	HADCM2 GHG+SUL. One member of the ensemble. Rescaled*, with medium climate sensitivity (2.5°C)	0.6°C	0.9°C	-1.0%	4.3%

* Scenarios rescaled using a technique to account for uncertainty in the magnitude of the climate sensitivity parameter (see Section 1.3), for further details see Arnell *et al.* (1997) and Mitchell and Johns (in press).

Table B.3 ***Percentage Change in Streamflow by the 2020s for England and Wales, by region (from Arnell et al, 1997)***

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
HADCM1													
South	3	5	5	-5	-3	-5	-7	-21	-30	-17	9	3	-1
East	8	5	6	-10	-6	-5	-4	-15	-19	-9	16	7	2
West	9	6	8	-5	-2	-1	2	-12	-13	1	16	5	4
North	14	6	8	-7	-7	0	10	0	1	13	20	7	8
GG1m													
South	7	9	8	7	4	3	-5	-4	-5	2	8	11	6
East	13	17	17	19	10	1	-10	-6	-2	7	19	21	13
West	5	10	6	8	8	0	-10	-3	0	7	12	10	6
North	8	11	6	3	12	3	-4	5	9	17	22	14	11
GS1m													
South	7	3	7	6	4	5	2	-4	-6	-5	-1	5	3
East	17	9	10	12	10	10	4	-5	-9	-8	-3	6	7
West	8	5	5	5	6	4	-1	-5	-5	1	4	5	4
North	11	7	4	3	9	6	-1	-1	-2	6	8	6	6
GS1t													
South	6	-5	-3	-2	3	-1	-17	-27	-16	-4	-17	-5	-5
East	4	2	-7	9	27	1	-21	-30	-23	-3	-17	-8	-2
West	5	-1	-3	9	25	1	-20	-24	-16	9	-3	5	1
North	8	10	3	15	36	-4	-16	-20	-7	21	6	3	6

Table B4 ***Percentage Change in Monthly Runoff by the 2020s for England and Wales, for Groundwater-Dominated Rivers (from Arnell et al, 1997)***

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
HADCM1													
Chalk (S)	0	1	0	-4	-5	-6	-6	-10	-14	-13	-4	0	-4
Chalk (E)	3	5	4	-1	-3	-5	-8	-15	-25	-20	-5	1	-2
Permo-T. (W)	4	4	5	-7	-4	-4	-3	-11	-13	-6	4	-1	-2
Permo-T. (E)	11	8	8	-4	-5	-2	0	-6	-9	0	20	11	6
Others	5	6	5	2	0	-1	-2	-8	-14	-12	1	4	1
GG1m													
Chalk (S)	11	13	14	14	12	8	1	-2	-2	1	7	11	9
Chalk (E)	21	20	16	14	12	11	6	2	0	4	11	19	15
Permo-T. (W)	13	19	15	16	14	6	-2	2	3	8	14	18	12
Permo-T. (E)	7	12	10	12	10	1	-6	-4	-2	7	19	19	10
Others	12	12	12	12	12	9	2	-2	0	5	12	15	10
GS1m													
Chalk (S)	12	11	10	10	10	10	8	3	0	-3	-2	3	7
Chalk (E)	14	12	12	10	9	9	7	1	-3	-4	-2	6	8
Permo-T. (W)	14	12	12	12	11	8	3	1	0	3	5	9	8
Permo-T. (E)	11	7	8	8	8	4	0	-3	-4	-1	5	8	6
Others	8	8	8	8	9	8	5	-1	-3	-2	3	5	6
GS1t													
Chalk (S)	-8	-6	-8	-6	1	-2	-13	-24	-28	-18	-19	-16	-11
Chalk (E)	3	-2	-3	-2	0	1	-8	-24	-20	-7	-15	-9	-4
Permo-T. (W)	4	-4	-6	9	25	2	-17	-19	-15	0	-9	1	-1
Permo-T. (E)	7	-3	-5	11	30	6	-14	-20	-19	-1	-7	4	1
Others	7	3	1	4	13	12	-3	-18	-20	-3	1	3	2

B1.1.2 Impacts on demand

Herrington [1] undertook the only major investigation into this issue in a study commissioned by the DoE. *Table B5* presents the overall results of the study with a breakdown of demand by sector for present day and the future with and without climate change (the climate change scenario is based on the CCIRG 1991). *Box B1* is taken from the executive summary of the report. The results show that the climate scenario may lead to a four per cent increase in overall demand by the 2020s. Particularly climate-sensitive sectors are air conditioning and agricultural irrigation water.

Box B1 Climate Change and Demand for Water in England and Wales

Quantitative results are established for climate-change-related forecasts of demand, using CCIRG (1991) scenarios for future climatic parameters. PWS domestic and measured demands may increase over 1991 to 2021, in the absence of climate change and any significant post-1991 move towards increased demand-management, by between **12%** and **38%** of 1991 demands (best estimate = **25%**). On our assumptions, climate change adds another **4%** to that increase (with a range of **3%** to **6%**). As expected, the effect of climate change on peak demands would be more significant: a typical public water supply peak seven day ratio, already forecast to grow from 1.21 to 1.36 by 2021, could increase further to about 1.42 because of warming. Direct abstractions for spray irrigation in the Anglian region are forecast to grow by **60%-75%** over 1991-2021 (range **30%** to **120%**). We estimate that climate change could add another **45%-50%** of estimated 1991 demands to that figure, concentrated in the summer months when supplies are scarcest. In addition, of course, all the PWS demand increases forecast above would feed through into direct abstractions.

Source: Herrington, 1996.

[1] Herrington, P.,1996 *Climate change and the demand for water.* HMSO, London. 164pp.

Table B5 Summary Table of 1991 and Forecast 2021 Demand for Water in South and East England, Without and With Climate Change

	1991	2021	2021	Effect of climate change on 2021 forecast	
	Best estimate (and range)	Without climate change central forecast (and range)	With climate change central forecast (and range)	Change Ml/d	Change %
I PUBLIC WATER SUPPLY					
Population (m.)	25.44m.	28.411m.	28.411m.	ZERO	ZERO
Domestic per capita (lhd)	147.0	178.4 (178.4±17.8)	185.6 (185.6±18.6)	+7.2 (lhd)	+4.0
Total Domestic	3740	5069 (4562-5575)	5273 (4746-5800)	+204	+4.0
Air conditioning	16.0 (7.4-25.9)	16.0 (7.4-25.9)	22.0 (9.2-38.8)	+6	+37.5
Golf Courses	3.3	4.8 (4.3-5.3)	5.0 (4.5-5.5)	+0.2	+4.2
Other Parks	24.5 (16.3-32.6)	30.4 (19.0-42.9)	31.6 (19.8-44.7)	+1.2	+3.9
Agriculture	125 (88-162)	153.8 (98-218)	172 (110-244)	+18.2	+11.8
Other Non-Domestic Measured	1770 (1715-1824)	1903 (1715-2098)	1903 (1715-2098)	ZERO	ZERO
Total Non-Domestic Measured	1939	2108 (1844-2390)	2134 (1859-2431)	+26	+1.2
UM: Commercial and Miscellaneous	432	464 (432-497)	464 (432-497)	ZERO	ZERO
Total PWS except leakage	6111	7641 (6838-8462)	7871 (7037-8728)	+230	+3.0
II DIRECT ABSTRACTIONS					
Spray Irrigation: Anglian	267	467 (347-587)	596 (442-748)	+129	+27.5
Spray Irrigation Rest of S&E	66	95 (71-119)	121 (91-152)	+26	+27.5
Total Spray Irrigation	333	562 (418-706)	717 (533-900)	+155	+27.5

B1.2 AIR POLLUTION AND POLLUTION DEPOSITION

B1.2.1 Simple Approaches

Climate change, air pollution and pollution deposition share some common causes. There are also links with the direct and indirect climatic effects of sulphate aerosols.(1) However there have been few attempts to assess the implications of climate change on air pollution and deposition.

(1)Mitchell J. F. B., Johns T. C., Gregory J. M., Tett S. F. B., 1995 *Climate response to increasing levels of greenhouse gases and sulphate aerosols*. Nature 376, 501-504.

The nature of any future precipitation changes will be important for pollution deposition rates. Heavier precipitation may offset reduced aqueous sulphate concentrations from reduced emissions. Research shows that a 50% reduction in emissions could lead to a reduction of sulphate wet deposition of only ~25%.[1] In addition, an increase in duration of precipitation would lead to a greater proportion of the atmospheric sulphate being scavenged.

The link between ambient pollution concentrations, wet deposition and atmospheric circulation, and the expectation that circulation will change as a response to global warming, has led to a limited number of studies. The supposition of circulation changes in the future has been the basis for many studies of other regional impacts of climate change [2]. Pitovranov [3] assessed the effects of supposed changes in frequency of European-scale synoptic patterns (Grosswetterlagen Types) on pollutant transport in Europe. He used an analogue approach to conclude that his assumed decrease in winter zonal types would lead to an increase in the frequency of pollutant transport from western to eastern Europe.

B1.2.2 Use of Global Circulation Models

Jones [4] adopted a more sophisticated and rigorous methodology. She considered projected changes in atmospheric circulation over Europe by comparing control and perturbed experiments by a GCM. Her study included one pollution monitoring station in the British Isles; Eskdalemuir in southern Scotland. She did not consider possible changes in pollution emissions; this was an assessment of the possible effects of climate change *alone*.

Precipitation was projected to increase by ~28% (greatest change in winter/spring). Decreases in aqueous concentrations were projected, but wet deposition increased: ammonium by 12% annually (22% in spring); nitrate by 19% (45% in spring); aqueous sulphate concentrations could not be projected because of large changes in sulphur emissions over the calibration period. Aerosol sulphate concentrations were projected to decrease by ~5%. Jones' work suggested a future increase in zonal flow over Europe, whereas Pitovranov had assumed a decrease in zonal flow. The overall conclusion of Jones' findings was that the changes in aqueous concentrations due to circulation changes alone were overshadowed by the changes in deposition caused by the projected changes in precipitation amount.

(1) Smith F. B. 1992 *Possible future trends in acid rain in the UK. In the treatment and handling of wastes* (Eds. Bradshaw A. D., Southwood R., Warner F.), Chapman and Hall, London.

(2) Hewitson B. C. and Crane R. G. *1992 Regional-scale climate prediction from the GISS GCM. Palaeogeography*, Palaeoclimatology, Palaeoecology 97, 249-267.

(3) Pitovranov S. E. 1988 *The assessment of impacts of possible climate changes on the results of the IIASA RAINS sulphur deposition model in Europe*. Water, Air and Soil Pollution 40, 95-119.

(4) Jones, P.D. and Conway, D 1997 *Precipitation in the British Isles: an analysis of area-average data updated to 1995*. International Journal of Climatology 17, 427-438.

Current deposition is in the range of critical loads for soft water lakes and acid grassland.[1] Jones' projected decrease does not bring any more ecosystems within critical loads range.
The study did not take into account changes in emission rates and patterns or changes in intensity, form and precipitation type (snow / rain).

B1.2.3 *Accounting for sulphur emission reductions and climate change*

The confounding effect of changing future pollutant and precursor emissions was addressed by Alcamo *et al*,[2] combining integrated assessment models of climate change and acidic deposition. Two sulphur emission scenarios were used. The 'Protocol Scenario' took into account the Second Sulphur Protocol and other planned reductions in the OECD regions. For non-OECD regions the assumption was that emission factors in all sectors are reduced by 50% between 2000 and 2050. The 'No Protocol Scenario' assumed no emission reductions in any region after 1990. The main output of the climate submodel are changes in precipitation and surface temperature. As far as can be determined, possible changes in circulation patterns (and their downstream effects on transport and deposition) have not been considered in this work.

Although Alcamo *et al.* concede that the downscaling procedure is very uncertain, they produced 'acidic' (ie sulphur-only) deposition maps at the country-scale. These were assessed in terms of exceedance of critical loads for sulphur, derived from a particular value for the Al:Ca ratio in soils which is deleterious to forests. The "5-percentile" critical load was adopted.[3] The estimates of area affected are *actual* land areas from grid-cells, rather than ecosystem area. The overall conclusion for the British Isles was a reduction in the area experiencing exceedance of critical load from (an estimated value from the published maps) 85-90% at 1990 to (an estimated) 65% by 2010 under the Protocol Scenario.

The study also used "change in potential vegetation" as an indicator of climate change impacts. Potential vegetation is the dominant vegetation (or biome) type that occurs under particular soil and climate conditions. 'Acidic' deposition and climate change indications were combined, with the conclusion that, by the middle of next century, around (an estimated) 30% of the British Isles' land area would be experiencing impacts from both perturbations (mainly in north and north-western England, central Wales, western Scotland and north-western Ireland). This is an interesting finding, given the projections of Jenkins *et al*.[4] that, on the basis of the current sulphur emission reduction scenarios alone, and not accounting for climate change, surface water acidification would not reverse.

[1] Hornung M., Bull K. R., Cresser M., Hall J., Langan S. J., Loveland P., Smith C., 1995 *An empirical map of critical loads of acidity for soils in Great Britain*. Env. Pollution 90, 301-310.

[2] Alcamo J., Krol M., Posch M. 1995 *An integrated analysis of sulfur emissions, acid deposition and climate change.* Water, Air and Soil Pollution 85, 1539-1550

[3] Downing R. J., Hettelingh J.-P., de Smet P. A. M. (Eds.) 1993 *Calculations and mapping of critical loads in Europe.* CCE Status Report, RIVM, Bilthoven, The Netherlands, 163 pp.

[4] Jenkins, A., Ferrier, R.C. & Cosby, B.J., 1997 *A dynamic model for assessing the impact of coupled sulphur and nitrogen deposition scenarios on surface water acidification*. Journal of Hydrology 197, 111-127.

Alcamo *et al.* 1995 conclude that, under the Protocol Scenario and on a European scale, the size of the area affected by climatic change (58%) by 2100 will be about the same as the size of area affected by 'acidic' deposition (54%) in 1990. There was also an indication that European ecosystems will continue to be under environmental stress despite controls on sulphur emissions. By the middle of next century, around 14% of Europe's area may be affected by both 'acidic' deposition and climate change. This study represented a first step in integrating an analysis of climate change and 'acidic' deposition, accounting for reductions in sulphur emissions, on a geographically detailed basis.

B1.2.4 Coupling of dynamic chemistry transport models and climate models; the way forward

A more sophisticated and, inherently, a more satisfactory approach is to link a regional chemistry transport model with a climate model. This has been done by Langmann and Graf.[(1)] Such an approach is suitable for an indication of the influence of the changing climate on the chemistry of the polluted atmosphere. In particular, it is the 'self-cleaning capacity' of the atmosphere which is of interest; it depends on the oxidation of trace gases by the hydroxyl radical and the washout and rainout of water soluble oxidation products. Higher emissions of CH_4, CO and short-lived VOCs seem to reduce hydroxyl radical concentrations, whereas a reduction in the stratospheric ozone column, and increasing water vapour concentration imply an increase of hydroxyl radical.[(2)] The chemistry transport model was modified for input data from a regional climate model which was nested in a global atmospheric circulation model.

The research conducted thus far consists of a validation exercise for the coupled models by simulating two European regional pollution episodes, one associated with a winter anticyclone; the other with a summer anticyclone. Both episodes led to considerable transport of pollution over the UK (the winter synoptic patterns were very similar to those identified, by *Davies et al*,[(3)] as being responsible for highly polluted wet deposition events in Scotland; above). The coupled model simulated atmospheric concentrations of sulphate, SO_2, HNO_3, NO_2, NH_3, and O_3. Comparison of the modelled and observed values for the winter episode was good for SO_2, the model was able to determine the oxidising capacity of the atmosphere, although NO_2 and HNO_3 concentrations were under-predicted. Under moderate photochemical activity, the models adequately reproduced observed O_3 concentrations in the summer episode, but peak (>40 ppbv) concentrations were underestimated, as were the peak concentrations of NO_2; sulphate and NH_3 were also underestimated.

(1) Langmann B. and Graf H.-F. 1997 *The chemistry of the polluted atmosphere over Europe: simulations and senstivity studies with a regional chemistry-transport-model.* Atmos. Environment 31, 3239-3257.

(2) Isaksen I. S. A. 1988 *Is the oxidising capacity of the atmosphere changing?* In: Dahlem Workshop Report: The Changing Atmosphere (Eds, Rowland F. S. and Isaksen I. S. A.). Wiley, New York., 141-171.

(3) Davies T. D., Tranter M., Jickells T. D., Abrahams P. W., Landsberger S., Jarvis K., Pierce C. E. 1992c. *Heavily-contaminated snowfalls in the remote Scottish Highlands: a consequence of regional-scale mixing and transport.* Atmos. Environment 26A, 95-112.

The overall conclusion from this study is that many improvements need to be made, but the model system is stable and sensitive enough to eventually be able to assess the influence of global climate change on the chemistry of the polluted atmosphere over Europe. This is an important conclusion, since such a dynamic chemistry / transport model system is the only satisfactory way to approach this issue.

Annex C

The International Negotiation Process

C1 THE INTERNATIONAL NEGOTIATION PROCESS

C1.1 THE BERLIN MANDATE

The 1st meeting of the Conference of the Parties (COP I), the decision making body under the UNFCCC, was held in Berlin in March-April 1995. The Conference decided that Articles 4.2(a) and 4.2(b), which contained the quantified commitments for Annex I parties, were inadequate. Accordingly, agreement was reached on a process leading towards the strengthening of the commitments. This agreement was termed the Berlin Mandate. It aimed as the priority for Annex I parties:

- to elaborate policies and measures, as well as
- to set quantified emission limitation and reduction objectives (QELROs) within specified time-frames such as 2005, 2010 and 2020.

It stated categorically there would be no new commitments for non-Annex I parties.

The process of developing these new commitments was undertaken under the auspices of the Ad hoc Group on the Berlin Mandate (AGBM) which met between mid-1995 and December 1997.

COP I also established two subsidiary bodies under the UNFCCC.

- The Subsidiary Body on Scientific and Technical Advice (SBSTA) which has the role of providing the COP with information and advice on scientific and technical matters.
- The Subsidiary Body on Implementation (SBI) which has the role of assisting the COP with the effective implementation of the Convention.

C1.2 THE SECOND ASSESSMENT REPORT AND THE GENEVA DECLARATION

In December 1995, the IPCC completed its 2nd Assessment Report (SAR) on the science of climate change, its impacts and response options. It went through an extensive peer review process and agreement by governments. It updated the original 1990 Assessment Report including providing revised projections of future climate change and levels of warming and sea-level rise.

Most notably it included a statement that has been widely quoted in the media, ie *the balance of evidence suggests a discernible human influence on global climate* [(1)]

This was a significant statement and, as part of the Summary for policy makers, represents the formally agreed statement of the IPCC concerning current understanding of the science of climate change. The more detailed text in the SAR explains that this initial step taken towards attributing climate change to anthropogenic factors is because of increasing correspondences between observations and model predictions.

The 2nd Conference of the Parties (COP II) was held in Geneva, Switzerland in July 1996. It included a meeting of the AGBM and a short Ministerial session during which Ministers agreed to the Geneva Declaration. The Declaration recognised and endorsed the SAR as the most comprehensive and authoritative assessment of the science of climate change, its impacts and response options. Ministers stated that it should form the basis for urgently strengthening action to limit and reduce greenhouse gases. The Ministers' Declaration instructed representatives to accelerate the negotiations. This gave an important impetus to the AGBM negotiations at their half-way stage.

C1.3 THE G8 SUMMIT AND UNGASS

At a June 1997 meeting in Denver of the leaders of the G7 plus the Russian Federation, climate change was raised as a significant issue by the EU members including the UK Prime Minister. Concern was expressed regarding the then US position. In response, the US accepted the need for greenhouse gas emissions to be reduced by 2010.

Immediately following this meeting, at the United Nations General Assembly Special Session (UNGASS or Earth Summit II) held in New York on 23-27 June 1997, President Clinton pledged to commit the US to realistic and binding limits "that will significantly reduce our emissions of greenhouse gases".

The final document from UNGASS is less forthright than the statements of individual countries such as the US. It stated that "the international community confirmed its recognition of the problem of climate change as one of the biggest challenges facing the world in the next century" [(2)] but text on the need for targets was stated in convoluted terms as "there is already widespread but not universal agreement that it will be necessary to consider legally binding, meaningful, realistic and equitable targets for Annex I countries that will result in significant reductions in greenhouse gas emissions …".

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(1) Houghton JT et al (1996) Summary for Policy Makers in Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. p4.

(2) Programme for the Further Implementation of Agenda 21 adopted by the Special Session of the General Assembly 23-27 June 1997.

Although there were still considerable differences between countries the significance of UNGASS was seen as placing climate change higher on the political agenda leading up to the third Conference of the Parties

Table C.1 The Kyoto Protocol

Greenhouse Gases Included
The Kyoto Protocol sets targets for developed country parties to limit emissions of an aggregate of six greenhouse gases:

- carbon dioxide
- methane
- nitrous oxide
- perfluorocarbons
- hydrofluorocarbons
- sulphur hexafluoride

Total emissions of the six gases are aggregated using 100-year Global Warming Potentials.

Targets
A series of differentiated targets are set for individual parties with a view to reducing overall emissions of these gases by at least 5% below 1990 levels in the budget period 2008 to 2012. The targets for individual countries are:

- 8% reduction for EU member states and the Community as a whole, most economies in transition and Switzerland;
- 7% reduction for the US;
- 6% reduction for Canada, Japan and Hungary;
- 5% reduction for Croatia;
- return to 1990 rates for New Zealand, Russia and the Ukraine;
- 1% increase for Norway;
- 8% increase for Australia; and
- 10% increase for Iceland.

The reductions are relative to a 1990 base year although targets for PFCs, HFCs and SF_6 may be set relative to a 1995 base year. The target years are for a budget period so that average emission rates in the budget period are to be at or below the targeted level. In addition, the Protocol states that by 2005 parties must have made demonstrable progress towards achieving their commitments.

Sinks
Parties may meet their targets through absorption by sinks in addition to reductions in emissions. Absorption by sinks is measured as the net changes in greenhouse gas emissions associated with afforestation, reforestation and deforestation since 1990. It is measured as verified changes in stocks of biomass. The details are still to be worked out.

Emissions Trading
Parties may meet their targets through emissions trading although the rules and guidelines are still to be agreed. The Protocol sets out more details for two approaches: project-based trading amongst Annex I parties which can occur through bilateral arrangements and project-based trading between Annex I and non-Annex I parties under the auspices of a Clean Development Mechanism which will provide for international verification of emission reductions.

Developing Countries
There are no new commitments for developing countries but existing commitments in Article 4.1 of the UNFCCC are reconfirmed.

Review Procedures
The Conference of the Parties will periodically review the Protocol in the light of best available scientific, technical, social and economic information and assessments.

C1.3.1 Target Levels

The Kyoto Protocol introduces a set of national targets (termed quantified emission limitation and reduction commitments) which were differentiated by country.

Table C.2 Gases Included in Targets in the Kyoto Protocol

Gas	Main Sources	Base Year
Carbon dioxide	Fossil fuel combustion, some industrial processes, waste incineration	1990
Methane	Fuel combustion, fugitive emissions from gas transmission and coal mining, agriculture (ruminant animals), waste decomposition	1990
Nitrous Oxide	Industrial processes (nylon manufacture), fuel combustion, agriculture	1990
Hydrofluorocarbons	Industrial processes (manufacture of fluids)	1990 or 1995
Perfluorocarbons	Industrial processes (aluminium smelting), solvent use	1990 or 1995
Sulphur hexafluoride	Industrial processes (magnesium industry, electrical insulation), solvent use	1990 or 1995

The full set of national targets is given in *Table C.3*. The targets agreed for Russia and the Ukraine are a surprising element of the Protocol. Both countries have emissions which have fallen substantially since 1990 and are not expected to increase to 1990 levels by 2008-2012 under business as usual; their target levels are likely to be a significant element of the discussions on rules for emissions trading (see below).

It is estimated that, in aggregate, this will result in a 5.2% reduction in emissions by 2008-2012 compared with 1990 although few data are available on HFCs, PFCs and SF_6 so this is very much a provisional estimate.

Table C.3 Quantified Emission Limitation or Reduction Commitments in the Kyoto Protocol

Quantified Emission Limitation and Reduction Commitment (% Change from 1990)	Party
+10%	Iceland
+8%	Australia
+1%	Norway
0	Russian Federation, Ukraine, New Zealand
-5%	Croatia
-6%	Canada, Japan, Hungary Poland
-7%	US
-8%	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK, European Community[(1)], Liechtenstein, Monaco, Switzerland, Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia

[(1)] The European Community is a party in its own right in addition to the individual member states.

Table C.4 EU Burden Sharing Agreement

Member State	Quantified Emission Limitation and Reduction Commitments (% Change in Emissions of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 from 1990)
Austria	-13
Belgium	-7.5
Denmark	-21
Finland	0
France	0
Germany	-21
Greece	+25
Ireland	+13
Italy	-6.5
Luxembourg	-28
Netherlands	-6
Portugal	+27
Spain	+15
Sweden	+4
UK	-12.5

Source: Community Strategy on Climate Change - Council Conclusions